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VISUAL SYSTEM OPERATIONAL EVALUATION

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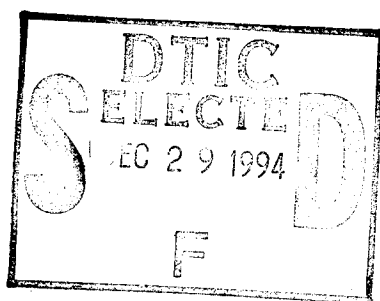
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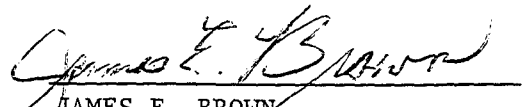AIR FORCE MATERIEL COMMAND
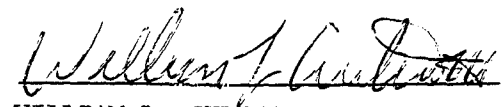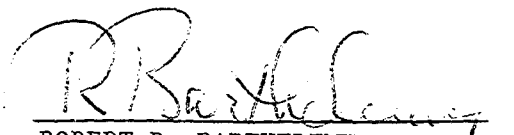WRIGHT PATTERSON AFB OH 45433-7126

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This technical report has been reviewed and is approved for publication.

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This evaluation was undertaken to identify the capability and limitations of current visual simulation to support low altitude flight training. Purpose was: (1) determine trainability of low altitude tasks on available visual display technology; (2) demonstrate current visual requirements; and (4) provide information and data to support future simulation acquisition decisions. Three visual simulation display technologies located at three different sites were evaluated: (1) dome display with head tracked area-of-interest, (2) rear-projection display, and (3) helmet mounted display. Highly experienced F-16C and F-15E instructor pilots evaluated each display technology. A standard list of evaluation tasks was used to evaluate each system in a mission context. Extensive questionnaires were completed and debriefings conducted to rate the training capability of the simulator to provide Mission Readiness(MR) and Continuation Training (CT) for operational aircrews (both wingman and flight leads). Major conclusions are (1) single ship air-to-ground tasks are trainable now with the right combination of database, image generator, and matched visual display system; and (2) current systems do not provide adequate resolution, contrast, and brightness to allow for dynamic air model assessment.

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PREFACE

This report summarizes the progress and findings to date of visual systems evaluations of three different image display technologies: (1) a two channel dome display; (2) a rear projection mosaiced display; and (3) a fiber optic helmet mounted display. The effort was funded and managed by the Training Systems Product Group, Aeronautical Systems Center, Wright-Patterson AFB Ohio. Evaluation pilots and weapons systems officers (WSOs) were provided through arrangement with the Air Combat Command (ACC), Langley Air Force Base, Virginia. Maj Jeff Valiton was the Program Manager, Mr. Tim Lincourt was the Lead Engineer, and Mr. Jim Brown was the Training Analyst. The ACC Project Manager was Maj Kirk Stant, 29th TSS, Eglin AFB, Florida. The evaluation team consisted of:

> Lt Col Don Poe, Evaluation Team Chief, and Lead Pilot
> Maj Kirk Stant, ACC Project Manager
> Maj Gary Allard, Evaluation Pilot
> Maj Ken Charpilloz, Evaluation Pilot
> Maj Keith Johnson, Evaluation WSO
> Maj Chris Singalewitch, Evaluation WSO
> Capt Matt Riehl, Evaluation Pilot
> Capt Mark Ware, Evaluation Pilot
> Capt Chris Lane, Evaluation Pilot
> Capt Darryl Roberson, Evaluation Pilot
> Capt Jeff Conner, Evaluation Pilot

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EXECUTIVE SUMMARY

The Visual System Operational Evaluation (VIS/EVAL) was initiated by the Training Systems Product Group (TPSG) as a result of the USAFE Low Altitude Training System (LATS) Requirements Analysis. USAFE was faced with loss of their low altitude flight training ranges and needed to explore alternatives. The LATS analysis indicated that modern visual flight simulation might be capable of providing the training necessary to sustain low altitude combat flight skills. This evaluation was undertaken to identify the capability and limitations of current visual simulation to support low altitude training.

Purpose of the program was to (1) determine trainability of low altitude tasks on available visual display technology; (2) demonstrate current visual simulation technology to users; (3) get feedback from those users to help define future visual requirements; and (4) provide information and data to support future simulation acquisition decisions. Three visual simulation display technologies located at three different sites were evaluated: (1) dome display with head tracked area-of-interest, (2) rear-projection display, and (3) a helmet mounted display.

The evaluation was planned and conducted with the support of Air Combat Command (ACC). A team of highly experienced F-16C and F-15E instructor pilots evaluated each of the three display technologies. A group of Weapon System Officers (WSOs) also evaluated the helmet mounted technology. A standard list of evaluation tasks from the USAFE LATS effort was used to evaluate each system in a mission context. At each site, evaluators flew four missions containing evaluation tasks capable of being flown in the flight simulator. The four missions consisted of a familiarization mission and three evaluation missions. The evaluation missions increased in order of difficulty. At the completion of each evaluation mission, extensive questionnaires were completed and debriefings were conducted to rate the training capability of the simulator for each task. Ratings addressed the capability of the system to provide Mission Readiness (MR) and Continuation Training (CT) for operational aircrews (both wingman and flight leads).

Results are presented for each of the three display systems evaluated. Major conclusions are (1) single ship air-to-ground tasks are trainable now with the right combination of database, image generator, and matched visual display system; and (2) current systems do not provide adequate resolution, contrast, and brightness to allow for dynamic air model assessment. Recommendations are made to identify future visual simulation training requirements.

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ABBREVIATIONS

A/A	Air-to-Air
AB	Air Base
ACC	Air Combat Command
AFB	Air Force Base
AFSC	Air Force Systems Command
AGL	Above Ground Level
AIM-9	Air Intercept Missile
AOI	Area-of-Interest
AZ	Arizona
CAF	Combat Air Forces
CT	Continuation Training
DART	Display for Advanced Research and Training
DB	Dive Bomb
DIS	Distributed Interactive Simulation
DMPI	Desired Munitions Point of Impact
DTOS	Dive Toss
EO	Electro-Optic
ESIG	Evans and Sutherland Image Generator
ESPRIT	Eye Slaved Projected Raster Inset Technology
FOHMD	Fiber-Optic Helmet Mounted Display
FOV	Field of View
FTU	Formal Training Unit
GE	Germany
HAS	High Angle Strafe
HD	High Dive
HMD	Helmet Mounted Display
HUD	Heads-Up Display
IG	Image Generator
IP	Instructor Pilot
IR	Infrared
KM	Kilometer
LAB	Low Angle Bomb
LALD	Low Angle Low Drag
LAN	Local Area Network
LAS	Low Angle Strafe
LATS	Low Altitude Training System
LOD	Level of Detail
Mini-DART	Smaller Version of the DART
MOD DIG	Modular Digital Image Generator
MRT	Mission Rehearsal Training
MTT	Multi-Task Trainer
NM	Nautical Miles
NR	Not Rated

OFT	Operational Flight Trainer
R&D	Research and Development
RAF	Royal Air Force
RWR	Radar Warning Receiver
SAM	Surface-to-Air Missile
SIF	Standard Interchange Format
SQ	Square
TACAN	Tactical Air Navigation
Texels	Texture Elements
TSRA	Training System Requirements Analysis
UK	United Kingdom
USA	United States of America
USAFE	United States Air Force in Europe
UT	Utah
UTD	Unit Training Device
VLD	Visual Level Delivery
WSO	Weapon System Officer
WST	Weapon System Trainer

SECTION 1 - INTRODUCTION

1.1 BACKGROUND

1.1.1 Ground-based simulator training for tactical fighter aircrews is limited by lack of adequate visual display systems. Efforts to develop visual systems with the capability to provide useful tactics training have met with limited success. A major requirement of tactical visual systems is that the display must have an instantaneously large field-of-view (FOV) both horizontally and vertically. This requirement has been difficult for industry to meet and still provide resolution and brightness that is adequate to realistically train tactical flying tasks. Other constraints have been in the area of data base size and detail. Fighter aircraft rapidly traverse long ranges in a very short time span. This places major emphasis upon data base development and image generation. They also operate at altitudes ranging from the surface to thirty or forty thousand feet. The fighter pilot needs to be able to recognize objects such as another F-16 with sufficient detail to visually identify other aircraft at realistic tactical ranges, assess aspect angle of another aircraft, fly tactical formation, and identify ground vehicles, roads and bridges. This wide range of requirements has made it difficult for industry to develop a display system adequate to meet the full range of fighter training requirements.

1.1.2 In the past, the Air Force has undertaken operational evaluations to determine if new advances in visual system technology provide capability to train tactical flying tasks. Among these efforts were Project 2235, Air-to-Ground Visual Simulation Demonstration (1976), Simulator Systems Comparative Evaluations (1977, 1979), and F-15 Limited Field of View Visual System Training Effectiveness Evaluation (1984). The general findings of these efforts indicated that existing visual systems could train some but not all critical tactical flying tasks.

1.1.3 In March 1989, the United States Air Force In Europe (USAFE) requested assistance from Air Force Materiel Command (AFMC) to meet its low altitude training needs for the 1990s. USAFE aircrews were limited to train at altitudes no less than 250 feet and at airspeeds no more than 475-550 knots. However, pilots indicated that in time of war, threat conditions might require them to fly at altitudes as low as 100 feet. A training systems requirements analysis (TSRA) was conducted based upon the F-16C and F-15E weapon systems. Recommendations based upon the analysis indicated that modern visual systems have the potential to significantly enhance available tactical aircraft training and may assist in slowing down the loss of critical low altitude flying skills that are not frequently practiced due to range or safety constraints (1991). The consensus of most engineering and training experts involved in the analysis was that current image generation technology was adequate to support low altitude training but that image display technology needs further assessment. To verify adequacy of image display technology to support low altitude training, an operational evaluation using aircrews was suggested.

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1.1.4 Recently, there have been many improvements in training equipment enabling technologies. These improvements are related to computer and networking technology.

1.1.4.1 As computers become more powerful and smaller, the capability of training devices increases while the size is reduced. This has led to the development of lower cost devices such as the recently contracted F-15 and F-16 Unit Training Devices (UTDs). These devices have nearly the same capability as an Operational Flight Trainer but only require the space of a desk. The UTDs can be operated in squadron ready rooms without special electric power or additional air conditioning. These devices are simple to operate; thereby eliminating requirements for a simulator operator. The pilot can initialize and operate the system whenever he wishes to train.

1.1.4.2 The advent of new networking technology will permit the connecting of several training devices to provide multiple aircrew mission training. The networking of trainers can be local or long distance. The local networking of trainers has been used for training multiple aircrews flying the same mission. However, long distance networking for aircrew training has yet to be implemented. Networking of training devices is required to permit realistic combat training on the ground in an environment closely replicating tactical combat conditions flown in actual aircraft. Tactical fighter aircrews enter combat in flights of four consisting of two elements of two aircraft. The flight lead, element lead, and wingman have similar but distinctly different tasks. The use of networking will permit ground training of these tasks in an integrated manner.

1.1.4.3 The networking of aircrew trainers for tactical combat training requires a full FOV display on those trainers. This full FOV display is needed by the pilot to perform the visual tasks encountered during combat. Today's combat aircraft are designed to provide the pilot with the maximum view of the terrain and sky. The pilot is trained to search both the terrain and sky for threats, targets, and friendly aircraft. As described later in this report, anything less than full FOV viewing limits combat tasks that can be performed in a trainer.

1.1.4.4 Another aspect of networking is cost of multiple training devices. As the number of training devices to be networked increases, the unit cost of these devices needs to decrease to be affordable. The UTD's lower cost will assist in reducing the cost of network trainers. However, the cost of a full FOV display could prohibit the networking of large number of devices. Thus, one of the purposes of this visual evaluation is to define the training capabilities of various image displays and image generation technologies. This information can then be used to select and define an affordable networked system of training devices with known capability.

1.1.5 Future tactical visual system requirements must be capable of expanding and enhancing training opportunities that are limited by airspace requirements, tactical range constraints, safety considerations, new threats, and increased weapon system complexity. Display technology has advanced since the last operational evaluation was conducted in 1984 and that new technology needs to be evaluated for possible application to new

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visual system requirements. Air Force Materiel Command initiated this operational evaluation with the assistance of Air Combat Command, to meet anticipated requirements.

1.2 AREAS TO BE INVESTIGATED. This evaluation focused upon image displays since it was the consensus of most engineering experts that this area is the prime issue for tactical visual training systems. This focus also served to simplify the planned evaluation. It was the consensus of engineering experts that development of image generation and improved data bases will be driven by commercial market forces such as the airline industry and computer advances.

1.3 PURPOSE: The purpose of this effort was to operationally evaluate available visual image display technology for potential application to operational training of tactical fighter aircrews.

1.4 SCOPE AND LIMITING FACTORS

1.4.1 The evaluation method used was an evaluation team composed of 8 tactical fighter instructor pilots and 2 instructor weapon systems operators, with current F-16C, F-15E, and F-111 background, to evaluate three different image display technologies located at three different sites. The image display technologies evaluated were: (1) a two-channel head-tracked dome display located at Evans and Sutherland Corporation, Salt Lake City UT; (2) a rear-projection mosaiced display, the Display for Advanced Research and Training (DART)* and a smaller display version (mini-DART)* located at Armstrong Laboratory, Williams Gateway Airport AZ; and (3) a fiber-optic helmet mounted display (FOHMD) located at CAE Stolberg, Stolberg GE. An engineering assessment for each device configuration was conducted to verify the current visual systems display and image generator attributes.
* Similar display technologies

1.4.2 The focus of the evaluation was the training capability of various image display technologies in the high threat low-altitude environment.

1.4.3 The evaluation was conducted over a seven month period beginning in January 1993 and ending in July 1993.

1.4.4 This evaluation was conducted at commercial and government flight simulator facilities. Evaluations were performed based upon facility availability and were often separated in time by as much as two months. It was recognized that experimental order effects, i.e., order in which a display technology was evaluated, would be present but had to be accepted as part of the evaluation.

1.4.5 The evaluation was an operational evaluation and was not structured as an experimental comparison. No transfer of training comparisons were made although

evaluation aircrews were asked to rate the training capability of the visual display system under evaluation. Each system was evaluated to assess the tasks that were rated trainable.

1.4.6 Due to large differences in weapon system components and performance capability, it was not possible to compare one visual system to another. Nor was a comparison intended. Rather, the intent of this evaluation was to rate the capability of a given display technology to support training of a selected set of 26 tactical tasks.

1.4.7 The limited availability of operational instructor pilots and instructor WSOs and the limited availability of the flight simulation facilities meant that the evaluation at each site had to be structured to be conducted and completed within one week. The evaluation team was composed of a small highly trained group of tactical fighter instructor pilots and instructor WSOs. Evaluators were given training on recognition of visual features related to displays, image generation, and data base. Evaluation WSOs were used to evaluate only the FOHMD technology at Site 3 and an F-4 FOHMD at Neuberg AB GE since these sites were the only sites with a WSO visual system. Due to operational duty commitments, not all pilot evaluators participated in every visual system evaluation. The number of evaluators at any one site varied between 5 and 7 instructor pilots.

1.4.8 Even though visual displays were the focus of the evaluation, and fidelity was not evaluated per se, it was recognized that cockpit differences, image generation, and data base capabilities impacted training capability ratings.

1.4.9 Only subjective aircrew data was gathered during the operational evaluation. Objective data such as bombing scores, hits, etc., was not available at all sites. Engineering data was furnished by the site organization and verified by evaluation team engineering personnel. The evaluation did not assess specific hardware. Therefore, operational suitability issues were not evaluated although general availability of systems was noted.

1.5 SPECIFIC OBJECTIVES

1.5.1 <u>Objective 1</u>. Evaluate the capability of selected image display technologies to support training of the 26 low altitude training tasks (Appendix A).

1.5.2 <u>Objective 2</u>. Evaluate the capability of the selected image display technologies to support mission qualification and continuation training.

1.5.2.1 <u>Subobjective 2-1</u>. Evaluate the capability of the selected image display technologies to support mission qualification training for wingman and flight lead.

1.5.2.2 <u>Subobjective 2-2</u>. Evaluate the capability of the selected image display technologies to support continuation training for wingman and flight lead.

1.5.3 <u>Objective 3</u>. Baseline and document the engineering attributes for each simulator configuration.

SECTION 2 - METHOD OF ACCOMPLISHMENT

2.1 METHOD OF TEST

2.1.1 <u>Operational Evaluators (Pilots and WSOs)</u>. The evaluation team was composed of a pool of eight fighter pilots and three weapon system operators (WSOs) specifically selected for their fighter experience and training background. All pilots and WSOs had extensive fighter experience in such weapon system such as F-4, A-10, F-15C, F-15E, and F-16. Two of the pilots had combat experience in the Middle East Conflict and two pilots were Fighter Weapons School graduates. During the evaluation period, one evaluation pilot was selected for the Thunderbird Demonstration Team. Average flying time for pilots was 1989 hours. Average instructor pilot time was 1039 hours. Of the three WSOs, one WSO participated at all evaluation sites and the other two WSOs went to Site 3 only to evaluate task training capabilities of the visual system for WSO tasks. All WSOs had instructor WSO experience and one had combat experience. Average flying time for WSOs was 2213 hours. Average instructor time for WSOs was 983 hours. Annex A contains the specific background of the evaluation pilots and WSOs.

2.1.2 <u>Training for Evaluators</u>. Since most of the evaluation pilots and WSOs had not been exposed to modern visual system technology, training for the team was provided in visual system technology and the evaluation process. Classroom instruction and demonstration training on visual system technology were given to evaluation pilots and WSOs for recognition of visual features related to visual displays, visual image generation, and data base. This training enabled the evaluators to assess the interrelationships of visual system components and to focus on the image displays for training capability ratings.

2.1.3 <u>Procedure</u>. The same general evaluation methodology was used at each site with minor differences as required by the system configuration and data base availability. This section addresses the operational evaluation and the engineering assessment.

2.1.3.1 **Operational Procedure (Pilots and WSOs).**

2.1.3.1.1 The evaluation was conducted at each site for a one week period. Four generic tactical missions were constructed to permit each pilot to evaluate 26 selected tactical flying tasks. Not all tasks were flown on each mission but the missions were developed to permit each of the tasks to be evaluated at least once during the evaluation missions if the site equipment and data base permitted. Each mission required approximately one hour to complete. The first mission was a familiarization mission. The next three missions were evaluation missions designed to evaluate air-to-surface tasks such as, tactical formation, low altitude evasive maneuvering, and low altitude air-to-surface weapon employment. The pilot tasks for the missions were based upon results from the USAFE Low-Altitude Training System (LATS) Requirements Analysis (1991) and modified by Air Combat Command. Annex B contains the pilot tasks and missions used in the evaluation.

2.1.3.1.2 For Site 3 only, four missions were developed to permit each WSO to evaluate 22 selected tactical tasks. These missions were the same length as the missions for evaluation pilots and were integrated into the missions for the pilot evaluators. The first mission was a familiarization mission; the next three missions were evaluation missions. The WSO tasks were identified as high value tactical flying tasks by Air Combat Command (ACC) and were correlated to tasks that would be performed by the pilots during missions at Site 3. Annex B contains the WSO tasks and missions used in the evaluation.

2.1.3.1.3 Approximately two days prior to arrival of the evaluation team, the lead evaluation pilot and WSO would visit each site to prepare for the evaluation. During this time, they would develop and fly the four generic missions to make adjustments in the flight profiles for the missions based upon limitations of the hardware and database capabilities of each site.

2.1.3.1.4 Upon arrival of the team, evaluators were given a briefing on the system at the site, the missions to be flown, evaluation procedures, and general plans for the week. Prior to each mission, evaluators were briefed on the specific mission to be flown.

2.1.3.1.5 Pilot and WSO evaluators flew each mission and then rated the tasks flown for training capability using the rating scale shown in Annex D. With the exception of the familiarization mission, all evaluators completed an extensive questionnaire, shown in Annex C, after each mission. This questionnaire was used as the basis for an evaluator debrief to explain ratings. The ratings and questionnaire data were later entered into computer data files that were used as an aid to data reduction. The debriefings were tape recorded and used as additional references to interpret the data.

2.1.3.2 Engineering Procedure. The engineering data collection was conducted as follows. Prior to going to the evaluation site, the engineering specialist requested specific engineering data from the site representatives. Two days prior to the team arrival, the engineering specialist visited the site and began collecting and verifying the data provided. The specialist remained on site throughout the evaluation and was responsible to track down limitations of the system and problems noted by the evaluation pilots and WSOs during their missions.

2.2 METHOD OF EVALUATION

2.2.1 Operational Evaluation. The percentage of acceptable or better ratings for each task was compared to the criteria to arrive at assessments. The measures of effectiveness were the evaluation pilot or WSOs subjective ratings and the evaluation team's assessment of the capability of each system to train pilots or WSOs in an operational training environment. The criteria were that at least 80 percent of the evaluators must rate each task a three or better (first criterion) or the Subobjective must receive an overall acceptable assessment by the evaluation team (second criterion).

2.2.2 Engineering Evaluation. The intent of the engineering evaluation was to document visual system performance as it existed at the time of the operational evaluation, not to assess the performance of each visual system. Using the pilot's assessment of the visual system's capabilities to train the identified tasks, and the engineering evaluation documented performance, systems engineers will be better able to translate the user's task requirements into a visual system performance specification.

2.3 SYSTEMS ENGINEERING DESCRIPTIONS

2.3.1 **Site 1: Two-Channel Head-Slaved Area of Interest (AOI) Dome/ ESIG 3000.** A detailed description of the visual system performance characteristics is presented in Objective 3 and Annex E.

2.3.1.1 Evaluation Cockpit and Aircraft Simulation. The evaluation cockpit was a generic aircraft cockpit mounted on a pedestal within a 24 foot diameter dome. The cockpit had instruments to represent standard aircraft flight parameters such as attitude, altitude, airspeed, vertical velocity, and engine instruments. It had a control stick and throttle controls that were representative of a generic fighter, and permitted control of flaps, speed brakes, and weapons release. Landing gear control was located on the panel. The cockpit had some weapons radar and fire control capability but not a fully capable integrated system found in current fighter aircraft. There was no Head-Up Display (HUD) and tactical instrument cross-check was all accomplished inside the cockpit. Sound and motion were not simulated. Flight performance of the simulated aircraft was representative of a generic high performance jet fighter aircraft (although not necessarily an F-16 or F-15E). Figure 2-1. shows the cockpit and dome.
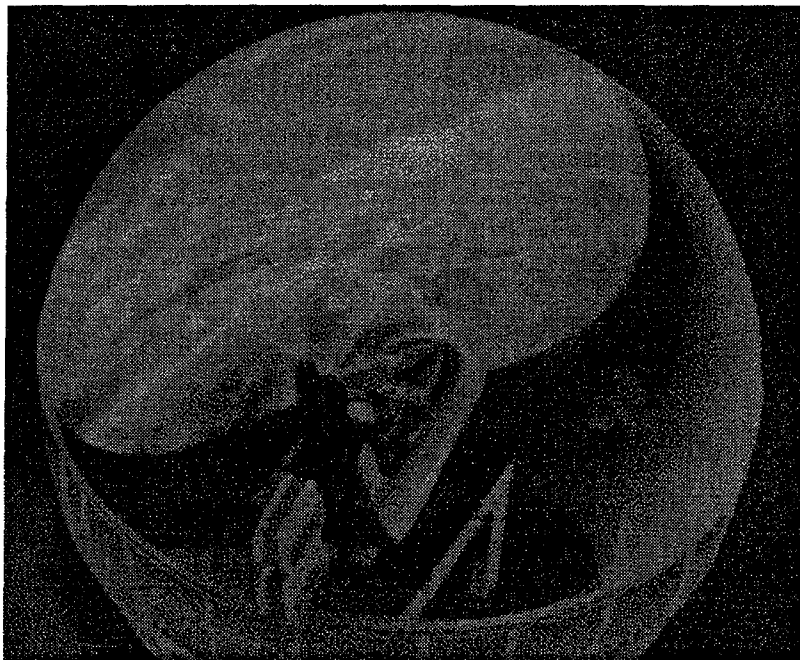
Figure 2-1. Picture of Cockpit and Display used in Site 1 Evaluation.

2.3.1.2 Image Display. The two-channel image display provided one channel for a head tracked background image with the other channel inserted, centered as an area of interest (AOI) scene. The AOI was superimposed on the background scene directly in front of the pilot's head. Both scenes were projected on the 24 foot dome by light valve projectors mounted above and behind the cockpit.

2.3.1.3 Image Generation. The image generator was a two channel ESIG 3000 built by Evans and Sutherland Corporation.

2.3.1.4 Data Base. The data base was representative of the Hunter-Liggett range in the USA (not correlated to real world).

2.3.2 **Site 2: Display for Advanced Research and Training (DART)/Compu-Scene IVA**. A detailed description of the visual system performance characteristics is presented in Objective 3 and Annex E.

2.3.2.1 Evaluation Cockpit. The evaluation cockpit was an F-15C Mission Tactics Trainer (MTT) developed for research and development by Armstrong Laboratory. The cockpit replicated the physical and functional controls and displays of the F-15C weapon system. The cockpit provided an integrated weapons radar and fire control system and had a projected HUD. Flight performance of the simulated aircraft was representative of the F-15C weapon system. The cockpit was situated inside the display. Figure 2-2. shows the cockpit and display.
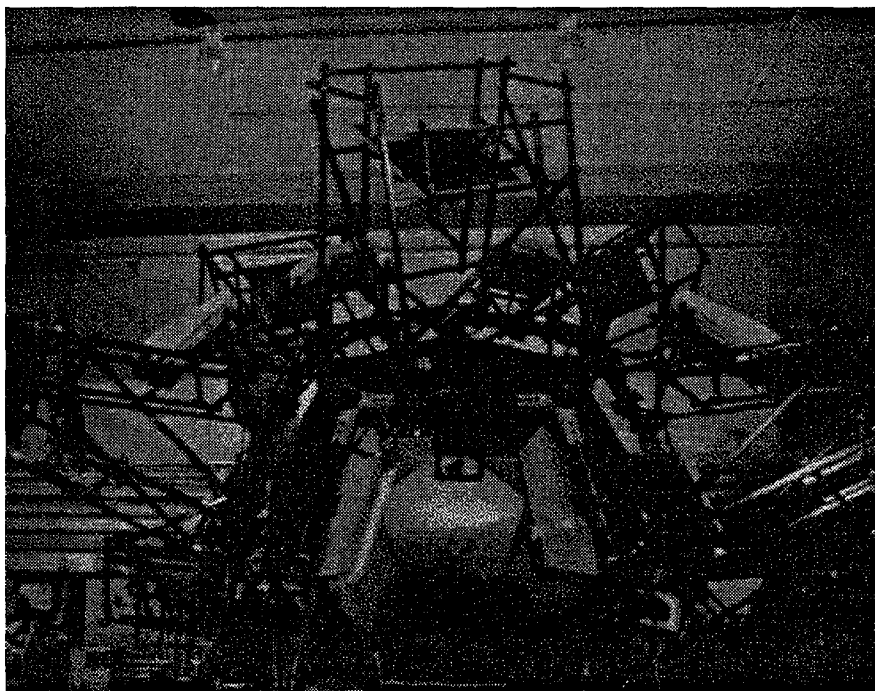
Figure 2-2.   Cockpit and Display for Advanced Research, Training (DART) at Site 2.

2.3.2.2 <u>Image Display</u>. The image display was a nine-channel mosaiced rear-projection flat screen wrap around display that provided a total FOV of 360 degrees horizontal by 110 degrees vertical.

2.3.2.3 <u>Image Generation</u>. A General Electric Compu-Scene IVA furnished the image generation for the evaluation.

2.3.2.4 <u>Data Base</u>. The data bases used in the evaluation were representative of a portion of the State of Washington and Germany.

2.3.3 **Site 2: Mini-Display for Advanced Research and Training (Mini-DART)/Compu-Scene IVA.** A detailed description of the visual system performance characteristics is presented in Objective 3 and Annex E.

2.3.3.1 <u>Evaluation Cockpit</u>. The evaluation cockpit was an F-15C Mission Tactics Trainer (MTT) developed for research and development by Armstrong Laboratory. The cockpit replicated the physical and functional controls and displays of the F-15C weapon system. The cockpit provided an integrated weapons radar and fire control system and had a projected HUD. Flight performance of the simulated aircraft was representative of the F-15C weapon system. The cockpit was situated inside the display. Figure 2-3. shows the cockpit and display.
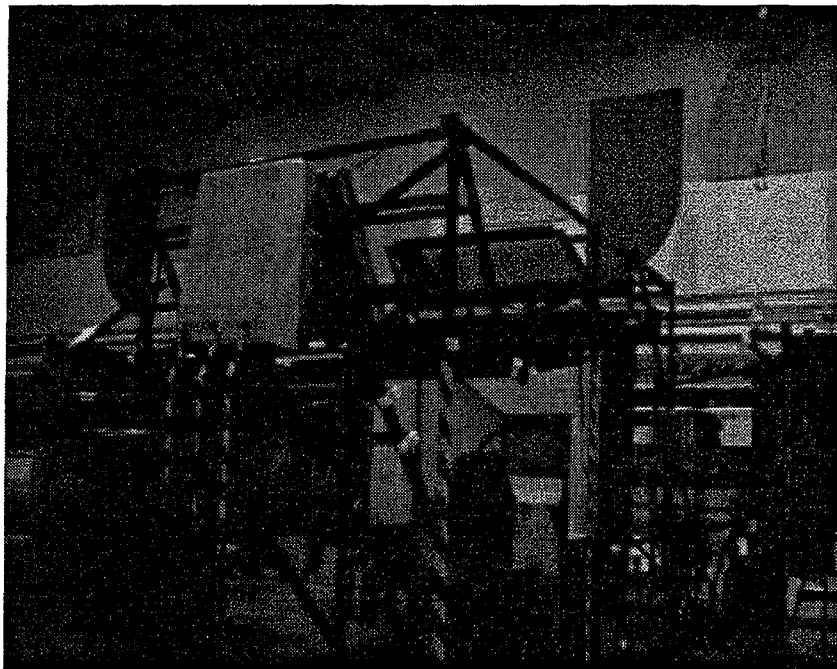
Figure 2-3. Cockpit and display for Mini-DART at Site 2.

2.3.3.2 <u>Image Display</u>. The image display was an eight-channel mosaiced rear-projection flat screen wrap around display that provided a total FOV of 360 degrees horizontal by 110 degrees vertical. This display was smaller volume than the DART. Also, the rear

quadrant display was a single flat screen that was lowered into place after the pilot had entered the cockpit.

2.3.3.3 Image Generation. A General Electric Compu-Scene IVA furnished the image generation for the evaluation.

2.3.3.4 Data Base. The data bases used in the evaluation were representative of a portion of the State of Washington and Germany.

2.3.4 **Site 3: Fiber Optic Helmet Mounted Display/ESIG-1000.** A detailed description of the visual system performance characteristics is presented in Objective 3 and Annex E.

2.3.4.1 Evaluation Cockpit. The evaluation cockpit was an Operational Flight Trainer (OFT) for the German Tornado Weapon System. It accurately replicated the physical and functional controls, flight systems, and flight characteristics of the Tornado aircraft. The cockpit provided an integrated weapons radar and fire control system and had a HUD. Fully integrated motion simulation was provided by (1) a six-post 60 inch stroke platform motion base, (2) a g-seat, and (3) a g-suit. Figure 2-4. shows the Tornado cockpit located on the platform motion system.
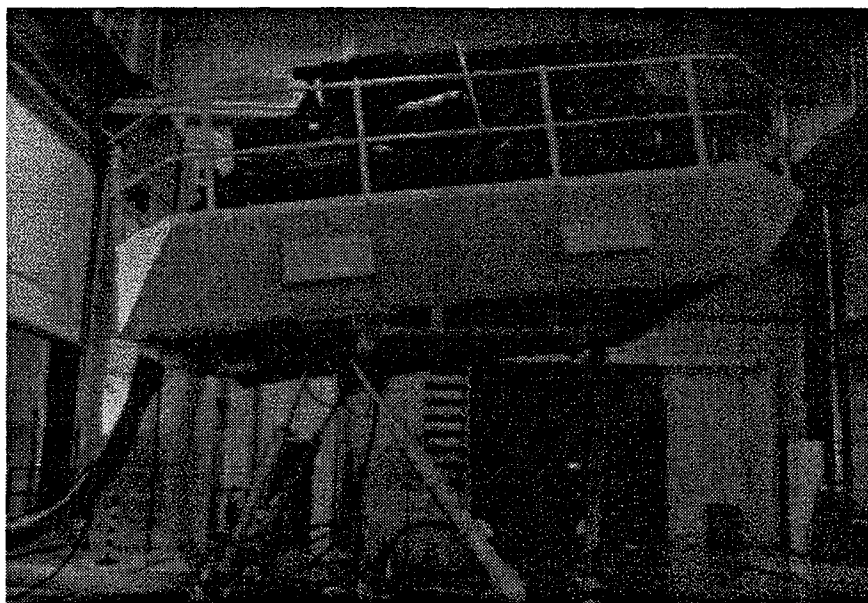
Figure 2-4.   German Tornado Cockpit located at Site 3.

2.3.4.2 Image Display. The three-channel fiber optic helmet mounted display (FOHMD) was fitted onto the pilot's and WSO's head after they had entered the cockpit. Figure 2-5. shows the FOHMD.

11
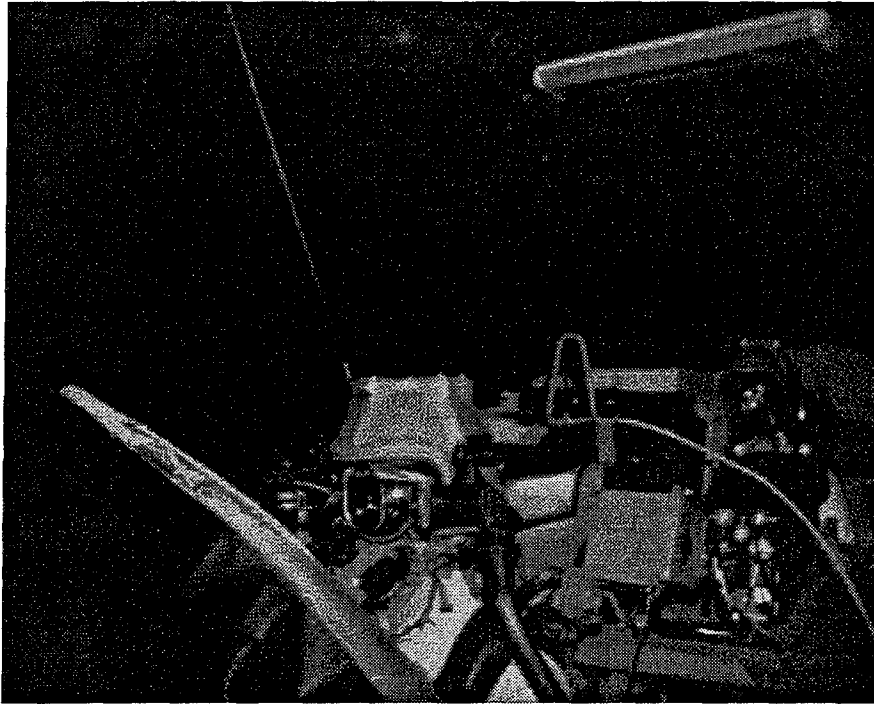
Figure 2-5. Fiber Optic Helmet Mounted Display (FOHMD) at Site 3.

2.3.4.3 Image Generation. An Evans and Sutherland ESIG-1000 provided the image generation for the evaluation.

2.3.4.4 Data Base. The data base used in the evaluation was an accurate representation of south central Germany.

SECTION 3 - RESULTS AND DISCUSSION

3.1 SPECIFIC OBJECTIVES.

3.1.1 <u>Objective 1</u>. Evaluate the capability of selected image display technologies to support training of twenty-six tactical combat low altitude training tasks (Appendix A).

3.1.1.1 <u>Measures and Criteria</u>. The measures and criteria for training effectiveness are discussed in paragraph 2.2.1.

3.1.1.2. <u>Results and Discussion</u>.

3.1.1.2.1 **Results and Discussion for Site 1: Two-Channel Area of Interest (AOI) Dome.**

3.1.1.2.1.1 From the list of 26 tasks that were initially identified (Table 3-1), 18 tasks were able to be evaluated during the missions flown.

Number	Pilot Tasks
1	Tanker rendezvous
2	Tactical formation from fingertip
3	Tactical formation above 500 feet
4	Combat descent
5	Tactical formation below 500 feet
6	Single ship low level
7	Visual low level navigate to initial point
8	Mutual support/lookout in various tactical formations
9	Detect visual threats
10	Detect electronic threats
11	Terrain Masking (direct/indirect)
12	Individual/formation threat reactions
13	Tactical instruments cross check
14	Visual target acquisition/identification
15	Coordinated tactical attack
16	Low altitude weapon delivery (LAS, LALD, LAB, VLD)
17	High altitude weapon delivery (HAS, HD, DB, DTOS)
18	Reform after tactical attack
19	Target reattack
20	Aircraft battle damage check
21	Low altitude intercept
22	AIM-9 employment
23	Low altitude air-to-air gun employment
24	Flight lead responsibilities
25	Wingman responsibilities
26	Situational awareness of tactical situations

Table 3-1   List of Pilot Evaluation Tasks for Two-Channel AOI at Site 1.

3.1.1.2.1.2 Tanker rendezvous was eliminated by team consensus since this task was not supportable by the simulation capability, is normally performed frequently during normal

operational training missions, and would have required unacceptable additional mission time to accomplish. The evaluation team believed that this capability would be partially evaluated in other tasks such as Low Altitude Intercept (Task #21) and Tactical Formation above and below 500 feet (Tasks #3 and #5) Seven tasks were not able to be performed due to simulator system limitations and were not evaluated. These seven tasks were: Task #10 Detect electronic threats, because the simulator lacked radar and RWR capability; Task #15 Coordinated tactical attack, because the simulator lacked a second cockpit (wingman) capability; Task #18 Reform after tactical attack, because the simulator lacked a second cockpit (wingman) capability; Task #20 Aircraft battle damage check, because the simulator lacked a second cockpit (wingman) capability; Task #22 AIM-9 employment, because the simulator lacked AIM-9 capability; Task#23 Low altitude A/A gun employment, because the simulator lacked adequate A/A capability; and Task #24 Flight lead responsibilities, because the simulator lacked a second cockpit (wingman) capability. It was believed that all of these limitations are correctable with improvements to the simulation system. However, the tasks would still need to be evaluated for training capability.

3.1.1.2.1.3 Of the remaining eighteen tasks, the two-channel AOI dome visual system was evaluated as being capable of supporting operational training for four tasks (see Table 3-2.). These four tasks received a rating of three or greater for at least 80% of the task ratings by the evaluation pilots. The four tasks that met the criterion were:

Task #11	Terrain Masking (direct/indirect) (89%)
Task #14	Visual Target Acquisition/Identification (80%)
Task #17	High Altitude Weapon Delivery (HAS, HD, DB, DTOS) (93%)
Task #19	Target Reattack (95%).

Table 3-2   Evaluation Tasks That Did Meet the Criterion on the Two-Channel AOI Dome Visual System. (Site 1)

Pilot comments indicated areas of improvements for these tasks even though they were rated acceptable (three or greater). Most frequently cited areas of improvement were: (1) wider AOI inset area and background scene and (2) improved resolution in background scene outside the AOI.
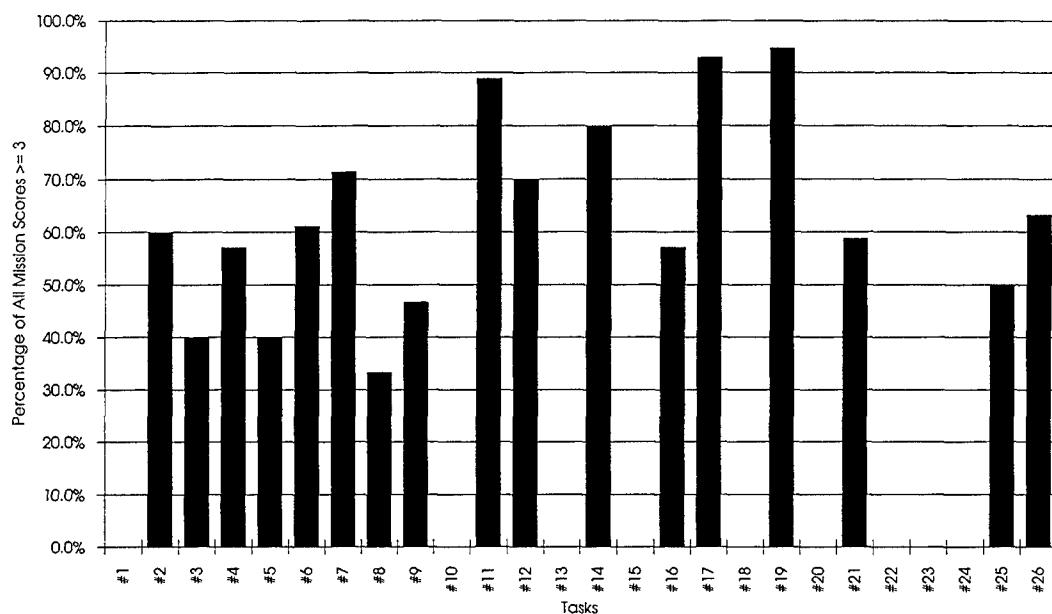
Figure 3-1.   Percentage of All Mission Training Capability Ratings of Three or More for All Evaluation Tasks for Two-Channel AOI Dome (Site 1).

3.1.1.2.1.4 Fourteen tasks did not meet the criterion for various reasons. These tasks and the percentage of IPs rating the task acceptable are shown in Table 3-3.

#	TASK	PERCENT OF IPs RATING ACCEPTABLE
2	Tactical Formation from Fingertip	60
3	Tactical Formation above 500 feet	40
4	Combat Descent	57
5	Tactical Formation below 500 feet	40
6	Single Ship Low Level	61
7	Visual Low Level Navigate to Initial Point	71
8	Mutual Support/Lookout in Various Tactical Formations	33
9	Detect Visual Threats	47
12	Individual/Formation Threat Reactions	70
13	Tactical Instruments Cross-Check	35
16	Low Altitude Weapon Delivery (LAS, LALD, LAB, VLD)	57
21	Low Altitude Intercept	59
25	Wingman Responsibilities	50
26	Situational Awareness of Tactical Situation	63

Table 3-3   Evaluation Tasks That Did Not Meet the Criterion for Two-Channel AOI Dome (Site 1).

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3.1.1.2.1.5 Tactical formation from fingertip, tactical formation above 500 feet, and tactical formation below 500 feet did not meet the criterion for the following reasons: Unrealistic head motion was required to place the high resolution AOI onto the wingman to check his position. Pilots indicated that this is not a normal flying habit. Rather they indicated fighter pilots normally move their eyes to pick up the target rather than make large head movements. Another frequently mentioned problem in performing these tasks was the target aircraft suddenly changed color to a bright green as distance increased to approximately 1200 to 1500 feet. This phenomenon was caused by the visual simulation changeover using a target projector to project the image of the target aircraft outside these distances. Pilots mentioned that within the above ranges, the target aircraft image would sometimes shift back and forth between bright green to the normal gray or camouflage color of the target aircraft. Several pilots reported the aircraft image would appear to jump to a slightly different location during the shiftover and there was a perceptible lag in the head-tracking of the target aircraft. Pilots indicated in the real world, at longer ranges, an aircraft silhouetted against the horizon will appear dark rather than bright green. The bright green was too easy to see and would detract from normal operational training. Lack of detail on the target aircraft outside 1200 feet made it difficult to fly formation. Pilots indicated they needed to be able to discern aircraft detail such as conformal fuel tanks, canopy, aircraft aspect angle, nose rate, and other cues to recognize aircraft movement at normal tactical ranges.

3.1.1.2.1.6 Combat descent did not meet the criterion due to difficulty in determining altitude visually. Several pilots indicated the ground appeared to be out of focus, however, buildings appeared to be in focus. Several indicated that other than the horizon, there were no adequate indications they were approaching the ground. Normal ground rush was not provided in the visual simulation. Small objects appeared to be blurry at longer ranges. Pilots also indicated accentuated head movements "to steer the AOI" were also required to perform this task. Again, the large head movements were not considered natural and impacted normal tactical cross-check pacing. The limited peripheral field of view and poor resolution in the periphery were mentioned as negative factors in the rating. Pilots indicated they pick up a large amount of required information from their peripheral vision. Another factor that contributed to the increased difficulty of this task was the lack of a HUD. Continuous tactical cross check from outside to heads down cockpit references for basic flight information reduced pilot effectiveness.

3.1.1.2.1.7 Single ship low level did not meet the criterion due to exaggerated head movement to move the AOI to the desired visual area, lack of adequate detail to maintain low altitude without reference to instruments, limited field of view and low resolution in the periphery, and lack of sufficient detail in data base (particularly forested areas). Pilots pointed out the requirement to "steer" the visual AOI caused them to spend too much time looking for an object of interest or caused them to fixate on the object. Both actions were detrimental to their cross-check. The majority of the pilots indicated the unnatural head movement needed to move the AOI made it difficult for them to fly low

altitude, check their six o'clock position for threats, tactically maneuver the aircraft, and navigate.

3.1.1.2.1.8 Visual low level navigate to initial point did not meet the criterion. Frequently cited problems in performing this task were the exaggerated head movements required to move the high resolution AOI inset and lack of resolution in the peripheral (background) scene. Pilots reported at low altitude, peripheral vision aids the pilot to determine aircraft position. They reported there were not enough peripheral cues in the scene, and that those cues that were available were not clear enough. In terms of the data base, the objects seemed to "float" above the ground; the ground appeared to be lower than these objects.

3.1.1.2.1.9 Mutual support/lookout in various tactical formations did not meet the criterion due to the exaggerated head movement to steer the AOI and the target projector providing an aircraft image that was too easy to see. The target projector issue has been previously discussed. This task requires extensive and frequent visual checking of areas surrounding the wing or flight lead aircraft while checking the six o'clock visual area of the pilots own aircraft for threats or other aircraft. Pilots reported they had to devote an inordinate amount of time in the simulator to perform this task because the head slaved AOI forced them to steer the high resolution AOI to the visual areas they were responsible for clearing. Also, they reported that they spent too much time on a given area or object because they tended to visually lock on to an area in order to pick up any threats or to keep an object within the high resolution AOI. Another problem was the peripheral area of the visual system did not cover their full field of view and that they could see black edges where the peripheral FOV of the visual system did not provide background scene coverage; this was particularly distracting to the majority of the pilots.

3.1.1.2.1.10 Detect visual threats did not meet the criterion because; (1) the aircraft threats were too easy to see due to their bright green color, (2) the surface to air missile (SAM) threats were not realistic due to visual display system resolution, lack of smoke and fire trails, and (3) unrealistic head movements were required to detect threats.

3.1.1.2.1.11 Individual/formation threat reactions did not meet the criterion due to a combination of factors. Unrealistic head movements were required to detect visual threats. Since there was no Radar Warning Receiver (RWR) indicator in the cockpit, this additional piece of information was missing to assist the pilots to determine threat location and type. Pilots normally obtain threat information from several critical sources, such as the RWR, and without this information, it made performance of the task unrealistic. As with visual threats, reaction to a threat often was late or not at all due to lack of smoke and fire trails in SAMs. Inability to recognize angle off, aspect angle, and energy state at realistic tactical ranges reduced threat reaction accuracy. The head slaved AOI required unrealistic head movements to acquire information and, once a threat was acquired, the tendency was to fixate on the area rather than lose visual contact.

3.1.1.2.1.12 Tactical instruments cross check did not meet the criterion due to lack of adequate instrumentation to perform the cross-check. The cockpit did not have a HUD, RWR indicator, or radar display. Without these systems, the task could not be realistically performed.

3.1.1.2.1.13 Low altitude weapon delivery (LAS, LALD, LAB, VLD) did not meet the criterion because of the head movement required to steer the high resolution AOI and the pilots indicated there was a noticeable lag in the visual system. The limited high resolution AOI forced unnatural scan patterns. The majority of the pilots reported the resolution was adequate for target identification and desired munitions point of impact (DMPI) selection. However, most pilots indicated the lack of peripheral cues and the limits in the high resolution AOI made scanning unnatural and detracted from weapons delivery. They reported having a less than full peripheral visual display made aircraft attitude and pop up attacks more difficult to evaluate.

3.1.1.2.1.14 Low altitude intercept did not meet the criterion primarily because the visual phase of a low altitude intercept requires radar work, switchology, geometry analysis, and threat analysis using both visual and avionic systems. Since the avionic systems lacked radar and a HUD, the task had to be performed as a totally visual task. This was not the manner in which the task would be performed or taught to a student. Pilots indicated they had to steer the visual display by turning their head directly toward the object they wanted to observe, this caused them to be "padlocked" on to a visual area rather than using their eyes to scan: another unrealistic manner to perform or teach the task. Pilots also observed the green aircraft projected by the target projector as being unrealistic. Several pilots indicated that the lack of resolution in the visual AOI and the target projector also caused them to be late in picking up the intercept aircraft as it transitioned from target projector to light valve imagery at 1200 feet. All of the aircraft were of the same green color beyond 1200 feet.

3.1.1.2.1.15 Wingman responsibilities did not meet the criterion due to the exaggerated head movements required to place the AOI on desired visual areas and the popping in of the high contrast green aircraft between 1200 and 1500 feet. The changeover to the target projector was distracting to the pilots.

3.1.1.2.1.16 Situational awareness of tactical situations did not meet the criterion primarily due to the lack of other than visual cues. Normally in tactical flying, pilots use many aircraft sensors in addition to the outside visual scene to maintain situational awareness. Several pilots reported that the lag in the visual scene response to head movements was sufficiently distracting to decrease their situational awareness to an unacceptable level. Pilots reported that the narrow AOI, reduced peripheral field of view, and difficulty in making altitude estimation solely from the visual display (since a HUD was not available) forced them to spend more time correctly positioning the simulator rather than employing it as a weapon system. For example, since there was no RWR, visual cues had to be used to pick up SAM launches or SAM sites. Due to the low resolution in the background scene, pilots often reported not seeing launches unless they

were placed the high resolution AOI directly on the SAM. This coupled with the other mission tasks being performed at low altitudes were cited as reasons for low situational awareness.

3.1.1.2.1.17 From the above discussion, many of the tasks that did not meet the criterion failed to do so due to lack of normal fighter avionics systems to accomplish the tasks. Evaluation pilots indicated tasks such as combat descent, detect visual threats, detect electronic threats, tactical instruments cross check, low altitude weapons delivery (LAS, LALD, LAB, VLD), low altitude intercepts, and situational awareness would have been rated higher in training capability if the cockpit had the instrumentation to perform the task.

3.1.1.2.2 **Results and Discussion for Site 2: Display for Advanced Research and Training (DART) and Mini-Display for Advanced Research and Training (Mini-DART).**

3.1.1.2.2.1 Starting with the list of 26 tactical flying tasks that were initially identified (Table 3-4), 24 tasks were evaluated in missions on the DART and Mini-DART.

Number	Pilot Tasks
1	Tanker rendezvous
2	Tactical formation from fingertip
3	Tactical formation above 500 feet
4	Combat descent
5	Tactical formation below 500 feet
6	Single ship low level
7	Visual low level navigate to initial point
8	Mutual support/lookout in various tactical formations
9	Detect visual threats
10	Detect electronic threats
11	Terrain Masking (direct/indirect)
12	Individual/formation threat reactions
13	Tactical instruments cross check
14	Visual target acquisition/identification
15	Coordinated tactical attack
16	Low altitude weapon delivery (LAS, LALD, LAB, VLD)
17	High altitude weapon delivery (HAS, HD, DB, DTOS)
18	Reform after tactical attack
19	Target reattack
20	Aircraft battle damage check
21	Low altitude intercept
22	AIM-9 employment
23	Low altitude air-to-air gun employment
24	Flight lead responsibilities
25	Wingman responsibilities
26	Situational awareness of tactical situations

Table 3-4   List of Pilot Evaluation Tasks for the DART and Mini-DART at Site 2.

3.1.1.2.2.2 Tanker rendezvous was not evaluated at Site 2 because the evaluation team believed that this task was not supportable by the simulation capability and is normally performed frequently during normal operational training missions and does not need to be taught in the simulator. Task #20, aircraft battle damage check, was not performed because of the unavailability of an aircraft model to fly the task upon. This task requires close maneuvering in relation to another aircraft. At the time of the evaluation, Site 2 had another R&D test in progress that precluded the accomplishment of this task.

3.1.1.2.2.3 Of the twenty-three remaining tasks, the DART visual system was evaluated as being capable of supporting operational training for ten tasks. These ten tasks received a rating of three or greater for at least 80% of the task ratings by the evaluation pilots (see Table 3.5). The ten tasks that met the criterion are shown below. The percentages of pilot ratings of three or better are shown in parentheses:

Task #4   Combat Descent (100%)
Task #6   Single Ship Low Level (90 %)
Task #7   Visual Low Level Navigate to Initial Point (100%)
Task #10   Detect Electronic Threats (100%)
Task #13   Tactical Instruments Cross-Check (100%)
Task #16   Low Altitude Weapon Delivery (LAS, LALD, LAB, VLD) (80%)
Task #19   Target Reattack (100%)
Task #22   AIM-9 Employment (93%)
Task #23   Low Altitude Air-to-Air Gun Employment (100%)
Task #26   Situational Awareness of Tactical Situations (80%)

Table 3-5   Evaluation Tasks That Did Meet the Criterion on the DART Visual System.
             (Site 2)

Although the tasks above were rated acceptable for training capability, pilots comments indicated areas of improvements. Most frequently cited areas were: (1) objects abruptly appeared on the display; (2) pilots had to rely more upon the radar altimeter and HUD to obtain altitude information; (3) due to inadequate resolution of the display, blemishes on the display screen were often mistaken for air-to-air threats; and (4) the on/off switching of the visual display channels located at the 6 o'clock position of the display needs to be improved so that it is less noticeable and distracting.
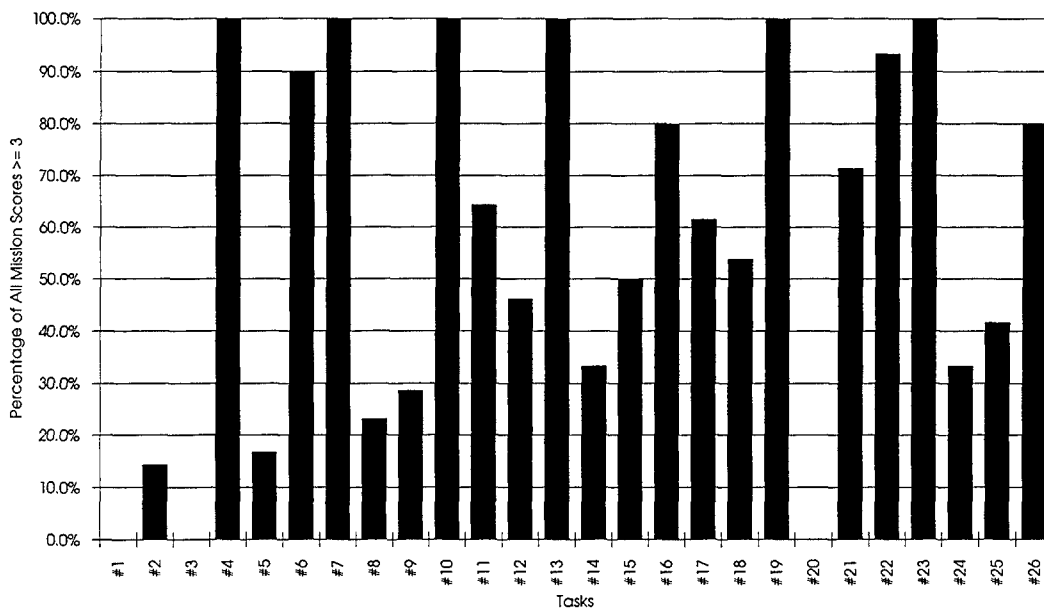
Figure 3-2.   Percentage of All Mission Training Capability Ratings of
              Three or More for All Evaluation Tasks on the DART at
              Site 2.

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3.1.1.2.2.4 Thirteen tasks did not meet the criterion for various reasons. These tasks and the percent of IPs rating the task acceptable are shown in Table 3-6.

#	TASK	PERCENT OF IPs RATING ACCEPTABLE
2	Tactical Formation from Fingertip	14%
3	Tactical Formation above 500 Feet	0%
5	Tactical Formation below 500 Feet	17%
8	Mutual Support/Lookout in Various Tactical Formations	23%
9	Detect Visual Threats	29%
11	Terrain Masking (Direct/Indirect)	64%
12	Individual/Formation Threat Reactions	46%
14	Visual Target Acquisition/Identification	33%
15	Coordinated Tactical Attack	50%
17	High Altitude Weapon Delivery (HAS, HD, DB, DTOS)	62%
18	Reform After Tactical Attack	54%
21	Low Altitude Intercept	71%
24	Flight Lead Responsibilities	33%
25	Wingman Responsibilities	42%

Table 3-6   Evaluation Tasks That Did Not Meet the Criterion on the DART Visual System. (Site 2)

3.1.1.2.2.5 Tactical formation from fingertip, tactical formation above 500 feet, and tactical formation below 500 feet did not meet the criterion for the following reasons: Pilots reported that they could not get close enough to fly reasonable fingertip formation. The majority of the pilots reported there was not enough detail to fly fingertip formation. Several pilots reported the 10 o'clock and 2 o'clock display screens appeared a little blurry compared to the front display screen and this contributed to the difficulty in accomplishing the task. For tactical formation, pilots reported the resolution of the formation aircraft outside 3000 to 5000 foot range was not adequate. They reported they could not accurately judge closure rates, heading changes, aspect angle and attitude changes in the formation aircraft. The result was they had to make more radio calls and rely on the TACAN or other sensors to maintain tactical formation. Pilots also reported the use of a strobe light flashing on the formation aircraft made it easier to see the other aircraft but made range assessment very inaccurate. Poor resolution and screen imperfections such as spots on the display or image imperfections caused difficulty at longer tactical ranges to determine whether it was a formation aircraft or a threat.

3.1.1.2.2.6 Mutual support/lookout in various tactical formations and detect visual threats did not meet the criterion. Pilots reported the resolution outside 3000 to 5000 feet was not adequate to perform the task without using more radio calls and other sensor information not normally required in actual flight conditions. Also, spots on the display screens or screen flickering were an additional distraction. Pilots reported they had to

make more radio calls and perform more inside the cockpit work due to the lack of visual aspect, speed, range, and nose position assessment capability. They also reported they could not see threat aircraft beyond ranges of three miles.

3.1.1.2.2.7 Terrain masking (direct/indirect) did not meet the criterion because pilots said there was insufficient scene detail to provide them with altitude cues. This was especially true over large brown and green colored areas. Pilots also reported the display did not possess sufficient resolution and the scene appeared too blurry to provide detail on land contours.

3.1.1.2.2.8 Individual/formation threat reactions did not meet the criterion. There was a lack of sufficient resolution outside the 3000 to 5000 foot range. The inability to see detail also caused them to mistake display blemishes as bandits. Pilots commented that with the threat coming at them nose on, they were not able to pick up the threat at the proper ranges. Also, they said their ratings on this task were influenced by the amount of extraordinary task loading they had to perform to fly tactical formation.

3.1.1.2.2.9 Visual target acquisition/identification did not meet the criterion. The lack of resolution outside 4000 feet made target identification occur too late. Pilots said target identification was satisfactory inside of this range.

3.1.1.2.2.10 Coordinated tactical attack did not meet the criterion due to of the lack of resolution. Pilots said if one of the aircraft responded to a threat, then returning to tactical formation became a major problem due to the difficulty of requiring wingman to compensate for a lack visual cues. Pilots had to spend more time monitoring their own formation position and back that up with a verbal description of their position over the radio.

3.1.1.2.2.11 High altitude weapon delivery (HAS, HD, DB, DTOS) did not meet the criterion. Targets appeared in the scene too late and lacked sufficient detail. Pilots said that the targets abruptly appeared in the scene. This rapid change of visual scene detail was related to the image generator. Several pilots reported that during weapon delivery they had to go well below normal pickle altitudes to visually acquire the target.

3.1.1.2.2.12 Reform after tactical attack did not meet the criterion because of the lack of adequate resolution outside the 3000 to 5000 foot range. Pilots said the visual cues were too poor for good tactical formation rejoins. They reported that because of the lack of visual resolution, they had to talk to their wingman to get within visual range (3000 to 5000 feet). Pilots indicated the visual display was not adequate to get back together outside this range.

3.1.1.2.2.13 Low altitude intercept did not meet the criterion. The target aircraft did not show up at the expected distances with the proper clarity. Pilots commented that using the radar to detect the target aircraft and then going visual at much closer ranges was

satisfactory . However, they indicated the task could not be accomplished using only the visual system.

3.1.1.2.2.14 Flight lead responsibilities and wingman responsibilities did not meet the criterion. The low resolution of the display forced the pilots to rely abnormally upon instrument cross checks to analyze closure and range due to degraded visual cues. Pilots reported lack of resolution and detail of the lead aircraft or wingman aircraft would not to permit realistic tactical formation work.

3.1.1.2.2.15 Results for the Mini-DART at Site 2 indicated the visual system was evaluated as being capable of supporting training for eight of the twenty-four tasks (see Table 3-7). These eight tasks received a rating of three or better for at least 80% of the task ratings by the evaluation pilots. For the most part, the results on the Mini-DART parallel those of the DART since they are relatively similar technology. The Mini-DART is slightly smaller and the rear display arrangement differs from the DART in that a single display panel is used rather than several display panels. There were some differences between the trainable tasks on the DART and the tasks rated trainable on the Mini-DART. Tasks rated as trainable on the Mini-DART were:

Task #4	Combat Descents (100%)
Task #7	Visual Low Level Navigate to Initial Point (80%)
Task #10	Detect Electronic Threats (100%)
Task #13	Tactical Instruments Cross Check (100%)
Task #19	Target Reattack (100%)
Task #21	Low Altitude Intercept (80%)
Task #22	AIM-9 Employment (100%)
Task #26	Situational Awareness of Tactical Situations (90%)

Table 3-7   Evaluation Tasks That Did Meet the Criterion on the Mini-DART Visual System. (Site 2)
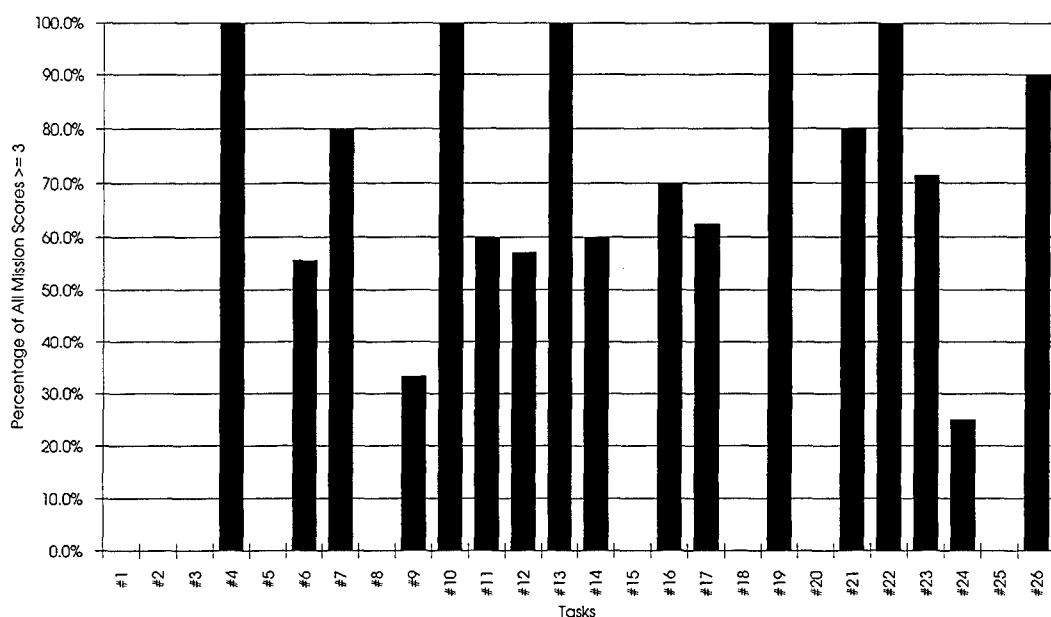
Figure 3-3.   Percentage of All Pilot Training Capability Ratings of Three or
More for All Evaluation Tasks on Mini-DART at Site 2

3.1.1.2.2.16 The differences in the tasks rated trainable and not trainable are as follows.
Task #6, Single ship low level was not rated as trainable on the Mini-DART where it had
been rated as trainable on the DART. Task #16, Low altitude weapon delivery (LAS,
LALD, LAB, VLD) was rated not trainable on the Mini-DART where it had been rated as
trainable on the DART. Pilot comments indicated that the close proximity of the display
screens in the Mini-DART may have been the cause of lower ratings. Pilots were not
Task 21, Low altitude intercept was rated trainable on the Mini-DART but not trainable
on the DART (71%) (Since the percentages do not differ by much (80% vs 71%) this
change may be a statistical anomaly resulting from slight rating shifts). Task 23, Low
altitude air-to-air gun employment, was rated as not trainable on the Mini-DART, but was
rated as trainable on the DART.

3.1.1.2.3 Results and Discussion for Pilots for Site 3: Fiber Optic Helmet Mounted Display (FOHMD).

3.1.1.2.3.1 Evaluation pilots flew 24 tasks from the list of 26 tasks that were initially identified (Table 3-8).

Number	Pilot Tasks
1	Tanker rendezvous
2	Tactical formation from fingertip
3	Tactical formation above 500 feet
4	Combat descent
5	Tactical formation below 500 feet
6	Single ship low level
7	Visual low level navigate to initial point
8	Mutual support/lookout in various tactical formations
9	Detect visual threats
10	Detect electronic threats
11	Terrain Masking (direct/indirect)
12	Individual/formation threat reactions
13	Tactical instruments cross check
14	Visual target acquisition/identification
15	Coordinated tactical attack
16	Low altitude weapon delivery (LAS, LALD, LAB, VLD)
17	High altitude weapon delivery (HAS, HD, DB, DTOS)
18	Reform after tactical attack
19	Target reattack
20	Aircraft battle damage check
21	Low altitude intercept
22	AIM-9 employment
23	Low altitude air-to-air gun employment
24	Flight lead responsibilities
25	Wingman responsibilities
26	Situational awareness of tactical situations

Table 3-8   Listing of Pilot Evaluation Tasks for FOHMD at Site 3.

3.1.1.2.3.2 Tanker rendezvous was eliminated by team consensus since this task was not supportable by the simulation capability and is normally performed during normal operational fighter training missions. Detect electronic threats was not evaluated in order to avoid security classification issues with the Tornado radar and RWR system. Lack of time to train pilots to proficiency in these systems, and a desire to avoid security classification issues precluded evaluation of the task.

3.1.1.2.3.3 Of the remaining 24 tasks, the FOHMD visual system was evaluated as being capable of supporting operational training for nine tasks. These nine tasks received a rating of three or greater for all task ratings by the evaluation pilots (see Table 3-9). The nine tasks that met the criterion are shown below. The percentage of pilot ratings of three or greater is shown in parentheses

Task #4	Combat Descent (100%)
Task #6	Single Ship Low Level (85%)
Task #7	Visual Low Level Navigate to Initial Point (80%)
Task #16	Low Altitude Weapon Delivery (LAS, LALD, LAB, VLD) (93%)
Task #17	High Altitude Weapon Delivery (HAS, HD, DB, DTOS) (93%)
Task #19	Target Reattack (86%)
Task #20	Aircraft Battle Damage Check (100%)
Task #22	AIM-9 Employment (100%)
Task #23	Low Altitude Air-to-Air Gun Employment (100%)

Table 3-9 Evaluation Tasks That Did Meet the Criterion on the FOHMD Visual System. (Site 3)

The majority of the pilots who evaluated the above tasks commented very favorably on the brightness of the display. Several areas of improvements were identified for the above tasks; (1) the ability to make head movement left or right and up to check high 12 o'clock is too restricted by the fiber optic cables; (2) instrument cross-checking in the cockpit was too time consuming due to the low visibility of instruments within the cockpit; transitioning from outside to inside the cockpit was very difficult particularly if the display information was on the attack radar display; (3) blemishes in the image display caused by broken fiber optic bundles were distracting since pilots had to differentiate whether it was a threat aircraft or a blemish; and (4) the eye tracked area of interest needed to be larger.
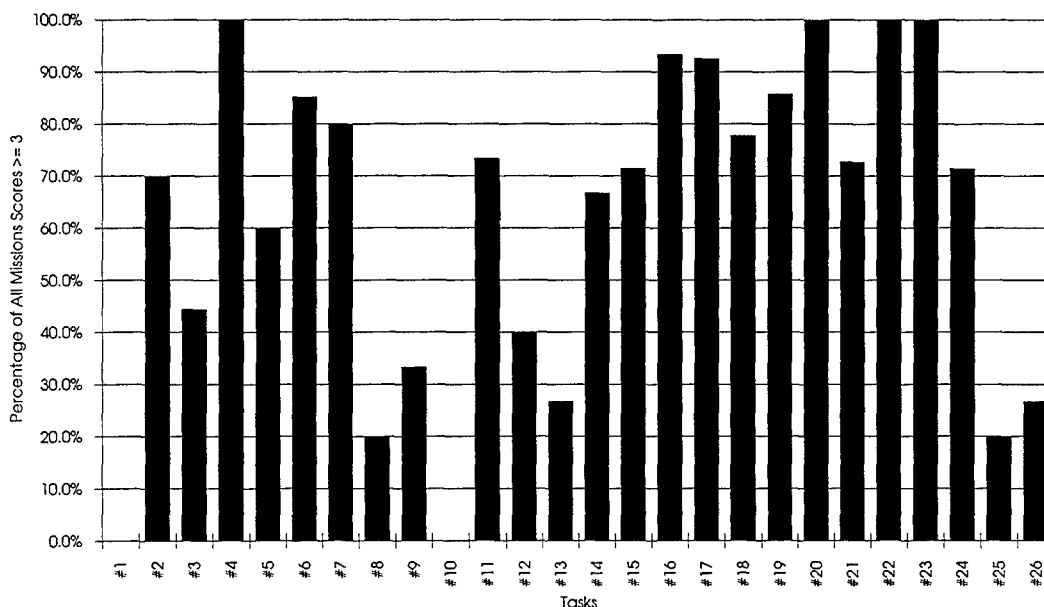
Figure 3-4. Percentage of All Pilot Training Capability Ratings of Three or More for All Evaluation Tasks on FOHMD at Site 3.

3.1.1.2.3.4 Fifteen tasks did not meet the criterion for various reasons. These tasks and the percentage of evaluation pilot's rating the task acceptable are shown in Table 3-10.

#	TASK	PERCENT OF IPs RATING ACCEPTABLE
2	Tactical Formation From Fingertip	70%
3	Tactical Formation Above 500 Feet	44%
5	Tactical Formation Below 500 Feet	60%
8	Mutual Support/Lookout In Various Tactical Formations	20%
9	Detect Visual Threats	33%
11	Terrain Masking (direct/indirect)	73%
12	Individual/Formation Threat Reactions	40%
13	Tactical Instruments Cross Check	27%
14	Visual Target Acquisition/Identification	67%
15	Coordinated Tactical Attack	71%
18	Reform After Tactical Attack	78%
21	Low Altitude Intercept	73%
24	Flight Lead Responsibilities	71%
25	Wingman Responsibilities	20%
26	Situational Awareness of Tactical Situations	27%

Table 3-10   Pilot Evaluation Tasks That Did Not Meet the Criterion on the FOHMD Visual System (Site 3)

3.1.1.2.3.5 Tactical formation from fingertip, tactical formation above 500 feet, and tactical formation below 500 feet did not meet the criterion for the following reasons: Pilots indicated the area of interest (AOI) was too small and the background imagery on the display lacked enough resolution to keep track of wing men while avoiding the ground and attempting to perform an instrument cross check. Two missions were flown with the eye tracker for the AOI not operating. Pilot comments for these two missions indicate the head tracked AOI forced the pilots to use exaggerated head movements to maintain sight of their wingman; they also said the resolution of the background was blurry (lacked resolution) and not adequate for general flying. For the remaining missions where eye tracking was operating, the broken fiber optic bundles were distracting and required more time to differentiate between blemishes and threat aircraft. This often forced changes in normal visual search patterns. Pilots also said that the low resolution of the background forced them to look directly at their wingman; whereas in actual flying, they use their peripheral vision to a large extent to maintain sufficient visual contact.

3.1.1.2.3.6 Mutual support/lookout in various tactical formations did not meet the criterion for the following reasons: Pilots said the bulkiness and difficulty of moving the helmet due to restrictions imposed by the fiber optic cables made it too difficult to check

the 6 o'clock or high 12 o'clock position. Broken fiber optic bundles also degraded the display. The pilots also reported that several times during their missions, the opposite eye from the direction that they were looking would black out when they moved their eyes to the extreme left, right, or up: this was extremely distracting and forced them to change their normal visual scan technique. At extreme ranges of 10,000 feet or more, pilots reported the broken fiber optic bundles made it difficult to distinguish between a threat and a blemish since both appeared as a black dot; this made them fixate on the spot to make identification. They also were unable to realistically accomplish this task at low altitude in a high threat environment due to inability to check their 6 o'clock. At low altitude they had to look forward to keep from impacting the ground. The majority of the pilots reported the resolution in the peripheral imagery of the display was not adequate for them to accomplish the task with or without eye tracking.

3.1.1.2.3.7 Detect visual threats, individual/formation threat reactions, and visual target acquisition/identification did not meet the criterion for the following reasons: Pilot comments indicated it was almost impossible to see a threat if it was not in the high resolution AOI. Visual pick-up of the threat at long ranges was too difficult. The oversized, slightly blurred threat image was confusing and did not offer distinctive line of sight cues when outside the AOI; often the threat was not detected until too late. Relative motion of a threat was difficult to identify at ranges greater than one mile. Broken fiber optic bundles initially appeared as threats: Pilots stated more time than usual was required to identify the threat because the targets were fuzzy. Air-to-ground targets appeared late and air-to-air targets were difficult to detect unless they were in the AOI. Head movement restrictions due to the fiber optic bundles made it difficult for pilots to check aft of 4 o'clock and 8 o'clock or high 12 o'clock position. Objects appeared too large at distances greater than two nautical miles. This caused the pilot to think that objects were closer than they actually were.

3.1.1.2.3.8 Terrain masking (direct/indirect) did not meet the criterion for the following reasons: Pilot interviews indicated the texturing of the ground needed improvement to provide better low altitude cues (this problem is a limitation of the image generator but manifests itself in this task). Three missions were flown without the eye-tracked AOI operating. Using only the head tracked AOI required the pilots to deviate from their normal flying procedures. For this task head-tracking was adequate for single ship, but inadequate in connection with formation/low level flying. With the head tracker only, it was too difficult to fly low altitude, stay in formation, cross check instruments, and adequately look outside. Pilots reported their visual lookout and cross check changed in order to keep sight of the other aircraft, avoid the ground, and cross check instruments. They said the cues for rising terrain were late and resulted in overreactions to changing terrain.

3.1.1.2.3.9 Tactical instruments cross check did not meet the criterion for the following reasons: Pilots indicated they could not easily look through the helmet mounted display optics into the cockpit and quickly gather the needed information. They stated they either had to fixate on an instrument too long or they cheated the system by looking under the

optics to get information they needed so they could resume out the cockpit visual tasks. Pilots believed that the brightness of the FOHMD affected the contrast needed for cockpit visibility.

3.1.1.2.3.10 Coordinated tactical attack and reform after tactical attack did not meet the criterion for the following reasons: Pilots reported that their visual search patterns were significantly changed; they had to look directly at their wingman in order to see them whereas in actual flight they would use their peripheral vision more. Also, the broken fiber optic bundles were distracting to the pilots. One evaluation pilot said the eye tracked AOI appeared to jump with eye movements and did not track smoothly.

3.1.1.2.3.11 Low altitude intercept did not meet the criterion for the following reasons: The pilots reported pure visual intercepts were generally not possible due to short range visual pick-up. Visually predicting target maneuvering at 2-5 nautical miles was not possible. Inside two nautical miles was good. The majority of pilots stated a need for improved resolution or a larger high resolution AOI field of view. They also tended to acquire the target late due to the inability to detect aircraft unless the aircraft was in the high resolution AOI. Pilots reported spending more time than normal looking for a visual target pick-up at what should have been normal ranges of 5-8 nautical miles.

3.1.1.2.3.12 Flight lead responsibilities did not meet the criterion for the following reasons. Pilots indicated that their visual search patterns were changed due to the lack of resolution in the background image of the FOHMD. To confirm the wing man's position, pilots reported they had to stare at them with the AOI longer than normal. Pilot interviews indicated that the limitations in head movement and graininess of the display due to the broken fiber optic bundles were limiting factors to teach this task.

3.1.1.2.3.13 Wingman responsibilities did not meet the criterion for the following reasons: Pilots stated lack of detail of the flight lead at ranges greater than 10,000 feet adversely affected their rating. The effort to make the FOHMD work effectively required too many abnormal work arounds. Time required to properly analyze flight lead's position in tactical formations was abnormally high. The restricted head movement due to the bulky nature of the FOHMD made it difficult to check 4 o'clock to 8 o'clock and high 12 o'clock positions. These are primary visual duties of a wingman. Another problem was poor resolution in the background forced the pilots to rely on the high resolution AOI rather than their peripheral vision. In several instances, the high resolution AOI could not track the quick eye movements that fighter pilots use to visually acquire information. In a high performance jet aircraft, pilots are taught to move their eyes rather than move their heads.

3.1.1.2.3.14 Situational awareness of tactical situations did not meet the criterion for the following reasons: The majority of evaluation pilots reported that they were unable to maintain situation awareness adequately using the FOHMD due to difficulty in moving the headgear to check 6 o'clock and the broken fiber optic bundles that forced them to take more time to differentiate between threat aircraft and blemishes. It was also difficult

to look into the cockpit while flying at low altitude or in formation. The limited peripheral visual cues did not aid the pilots to maintain situational awareness when looking aft of 3 o'clock to 9 o'clock.

3.1.1.2.4 Results and Discussion for WSOs for Site 3: Fiber-Optic Helmet Mounted Display (FOHMD).

3.1.1.2.4.1 For Site 3, 22 tasks were identified for possible evaluation by the WSO evaluators (see Table 3-11). Of these tasks, 21 tasks were able to be evaluated during the WSO missions using the FOHMD.

Number	WSO Tasks (Site #3A Only)
1	Single ship low level
2	Visual low level navigate to initial point
3	Mutual support/lookout in various tactical formations
4	Intraflight coordination/communication
5	Intercockpit coordination/communication
6	Detect visual threats
7	Detect electronic threats
8	Tactical instruments cross check
9	Visual target acquisition/identification
10	Coordinated tactical attack
11	Low altitude weapon delivery (Radar/EO)
12	High altitude weapon delivery (Radar/EO)
13	Reform after tactical attack
14	Target reattack
15	Aircraft battle damage check
16	Low altitude intercept
17	Situational awareness of tactical situations
18	Direct tactical formation
19	Direct individual/formation threat reactions
20	Direct target attack/reattack
21	Direct reform
22	Direct egress

Table 3-11   Listing of Tasks Evaluated by WSOs on FOHMD at Site 3.

3.1.1.2.4.2 Detect electronic threats was not evaluated. Lack of time to train WSOs to proficiency in these systems and desire to avoid security classification issues precluded meaningful evaluation of the task.

3.1.1.2.4.3 Of the remaining 21 tasks, the FOHMD visual system was evaluated as being capable of supporting operational WSO training for 11 tasks. These 11 tasks received a rating of three or greater for all ratings of the task by the WSOs (see Figure 3-5.). The 11 tasks that met the criterion are shown below. The percentage of WSO ratings of three or greater is shown in parentheses:

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Task #1	Single Ship Low Level (83%)
Task #2	Visual Low Level Navigate to Initial Point (100%)
Task #4	Intraflight Coordination/Communication (83%)
Task #5	Intercockpit Coordination/Communication (100%)
Task #10	Coordinated Tactical Attack (100%)
Task #11	Low Altitude Weapon Delivery (Radar/EO) (100%)
Task #12	High Altitude Weapon Delivery (Radar/EO) (100%)**
Task #14	Target Reattack (80%)
Task #15	Aircraft Battle Damage Check (100%)
Task #20	Direct Target Attack/Reattack (83%)
Task #22	Direct Egress from Target Area (100%)

** This task was evaluated once by a single WSO and given a rating of three. Although the number of evaluations of the task was not sufficient to be reliable, it is included here for information only.
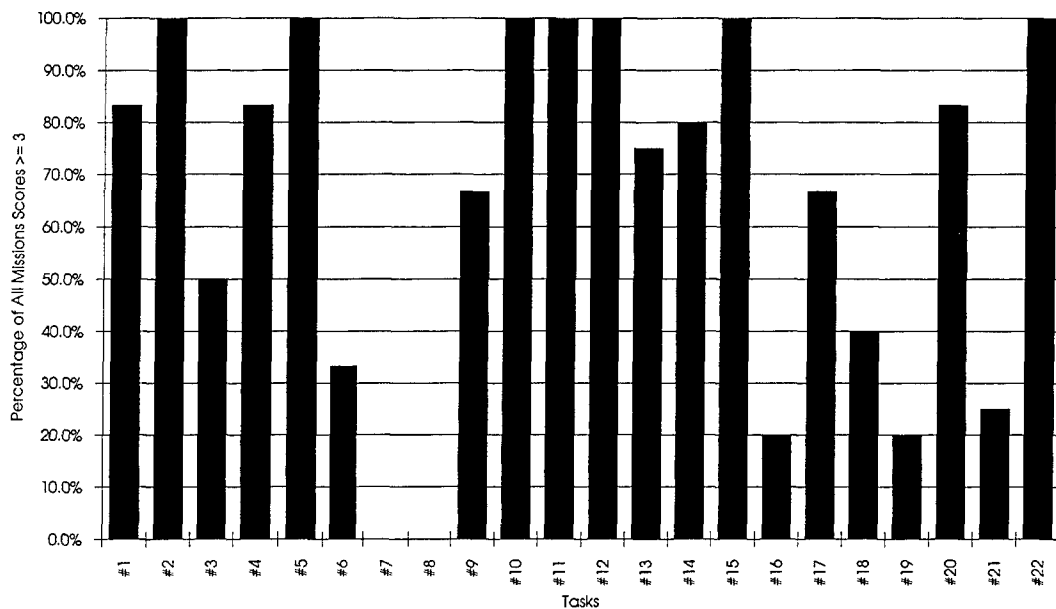
Figure 3-5. Percentage of All WSO Training Capability Ratings of Three or More for All Evaluation Tasks for FOHMD at Site 3.

3.1.1.2.4.4 Ten tasks did not meet the criterion for various reasons. These tasks and the percentage of evaluation WSOs rating the task are shown in Table 3-12.

#	TASK	PERCENT OF WSOs RATING ACCEPTABLE
3	Mutual Support/Lookout in Various Tactical Formations	50%
6	Detect Visual Threats	33%
8	Tactical Instruments Cross Check	0%
9	Visual Target Acquisition/Identification	67%
13	Reform After Tactical Attack	75%
16	Low Altitude Intercept	20%
17	Situational Awareness of Tactical Situations	67%
18	Direct Tactical Formation	40%
19	Direct Individual/Formation Threat Reactions	20%
21	Direct Reform	25%

Table 3-12   WSO Evaluation Tasks that did Not Meet the Criterion on the FOHMD Visual System (Site 3).

3.1.1.2.4.5 Mutual support/lookout in various tactical formations did not meet the criterion for the following reasons: Both WSOs indicated that they were unable to perform this task adequately since they were unable to check their six o'clock position for threats. The difficulty of moving the FOHMD due to the routing of the fiber optic cables was the primary problem. Difficulties with the eye-tracking contributed to low ratings for this task on two missions; on these missions only a head tracked AOI was available. WSOs indicated that there was extra workload when the eye tracker was riding too high. They also stated that the lack of aircraft definition made it hard to judge whether the lead aircraft was closing or diverging. However, the object detail did allow for sighting and identification of other aircraft.

3.1.1.2.4.6 Detect visual threats did not meet the criterion for the following reasons: WSOs indicated that ratings of this task were impacted by the difficulty of moving the FOHMD due to the routing of the fiber optic cables. They indicated that their normal scan patterns were impacted; they could not check high 6 o'clock due to the visual system limits. They also stated that there was not enough detail and contrast of threats to give early acquisition of threats at a great distance. Broken fiber optic bundles gave the display a "dirty canopy" appearance and affected visual threat acquisition.

3.1.1.2.4.7 Tactical instruments cross check did not meet the criterion for the following reasons: This task was difficult to perform due to the difficulty of looking through the FOHMD into the cockpit. Even with back lighting, the instruments were difficult to see

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and quickly get information. WSOs indicated that trying to glance at the Tornado moving map was impossible. They indicated that they had to stare at the display to discern map features and that this was not realistic. WSOs were concerned that with the extensive use of multi-function displays in the F-15E the FOHMD would not be able to train this task. There was too much time spent looking at the displays. Both WSOs indicated that the only way they could see the information they needed for the mission was to peer around or under the optics.

3.1.1.2.4.8 Visual target acquisition/identification did not meet the criterion for the following reason: The visual target could not be acquired and identified at normal ranges. WSOs had to wait until the visual target was closer than usual and this was not acceptable. Part of the problem was due to the screen door effect caused by the broken fiber optic bundles. The broken bundles reduced the brightness and also forced the WSOs to have to sort visual targets from the dark spots caused by the broken fiber optic bundles.

3.1.1.2.4.9 Reform after tactical attack did not meet the criterion for the following reasons: WSOs stated that they were unable to see wingman at normal reform ranges. They also indicated that the visual display did not give them the normal contrast between aircraft and the sky and that they had to spend more time trying to visually acquire their wingman.

3.1.1.2.4.10 Low altitude intercept did not meet the criterion for the following reasons: WSOs indicated that there was not enough detail and contrast for threat aircraft to give early acquisition and identification. This made the task of intercept difficult to perform. The broken fiber optic bundles contributed to the dirty canopy look of the FOHMD and affected target identification.

3.1.1.2.4.11 Situational awareness of tactical situations did not meet the criterion for the following reasons: WSOs stated that they rated this task low because they were unable to spot bandits (threat aircraft) at normal ranges. Broken fiber optic bundles contributed to this problem because WSOs indicated that they had to spend too much time trying to visually acquire threats or to assure themselves that a visual object was not a threat.

3.1.1.2.4.12 Direct tactical formation did not meet the criterion for the following reasons: WSOs indicated that they had to work too hard to keep visual contact with flight leads or wingman. Much of this they said was due to the low contrast of the visual image of other formation aircraft in the high resolution AOI. Another part of the problem was the difficulty of moving the helmet to check aft of the aircraft. To direct tactical formation, the WSO has to keep the other aircraft in sight at all times.

3.1.1.2.4.13 Direct individual/formation threat reactions did not meet the criterion for the following reasons: Both WSOs indicated that they were unable to scan an area visually as rapidly as they normally do in actual flight. This was due to the low contrast of aircraft against the sky. This made it much more difficult to detect and then identify an aircraft.

The WSOs also indicated that the broken fiber optic bundles forced them to spend more time than normal just to identify that a spot was not a threat aircraft. They also indicated that threats would appear suddenly and that it was difficult to judge their heading. Aircraft could not be detected at normal ranges and were not as sharply defined as they are in the real world. The difficulty of moving the FOHMD to check aft of the 4 o'clock and 8 o'clock position also was mentioned as a problem.

3.1.1.2.4.14 Direct reform did not meet the criterion for the following reason: Both WSOs indicated that the low visual contrast of the lead aircraft against the sky made it too difficult to determine which way lead was heading.

3.1.2. Objective 2. Evaluate the capability of the selected image display technologies to support mission qualification and continuation training.

3.1.2.1 Subobjective 2-1. Evaluate the capability of the selected image display technologies to support mission qualification training for wingman and flight lead.

3.1.2.1.1 Measures and Criteria. The measures and criteria for training effectiveness are discussed in paragraph 2.2.1.

3.1.2.1.2 Results and Discussion. Data for this objective was obtained at the conclusion of the final evaluation mission. The questionnaire requested the evaluator to rate the potential of the visual system to support mission readiness training. Each of the tasks flown in the three evaluation missions was evaluated. The intent was to obtain an overall assessment of the evaluators across all missions. The assessment requested the evaluators to base their ratings upon their own experience in training students and their past operational experience. It should be recognized that this rating was a single rating reflecting the evaluator's assessment of the potential of the visual system to support operational mission readiness training. Therefore, the results may be expected to differ from results in Objective 1.

3.1.2.1.2.1 Results and Discussion for Site 1:   Two-Channel Area of Interest (AOI) Dome.

3.1.2.1.2.1.1 Eighteen tasks flown by the evaluation pilots were rated for the potential of the visual system to support mission readiness training for wingman (see Figure 3-6.). The results show that one task received a rating of three or greater for at least 80% of the task ratings by the evaluation pilots. The task that met the criterion was: Task #17, high altitude weapon delivery (HAS, HD, DB, DTOS).
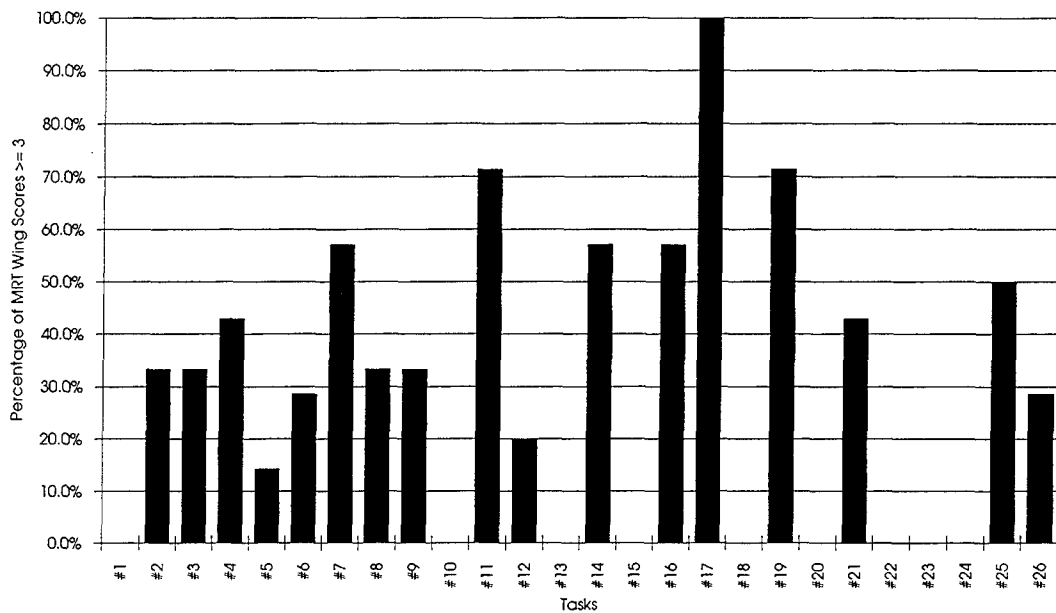
Figure 3-6.   Percentage of All Pilot Training Capability Ratings of Three or More for Wingman Mission Readiness Training on Two-Channel AOI (Site 1).

3.1.2.1.2.1.2 The eighteen tasks flown by the evaluation pilots on the Two-Channel AOI Dome also were rated for the potential of the visual system to support mission readiness training for flight leads (see Figure 3-7.). The results show that four tasks received a rating of three or greater for at least 80% of the task ratings by the evaluation pilots. The tasks that met the criterion were:

Task #7	Visual Low Level Navigate to Initial Point (100%)
Task #11	Terrain Masking (direct/indirect) (100%)
Task #17	High Altitude Weapon Delivery (HAS, HD, DB, DTOS) (100%)
Task #19	Target Reattack (100%)

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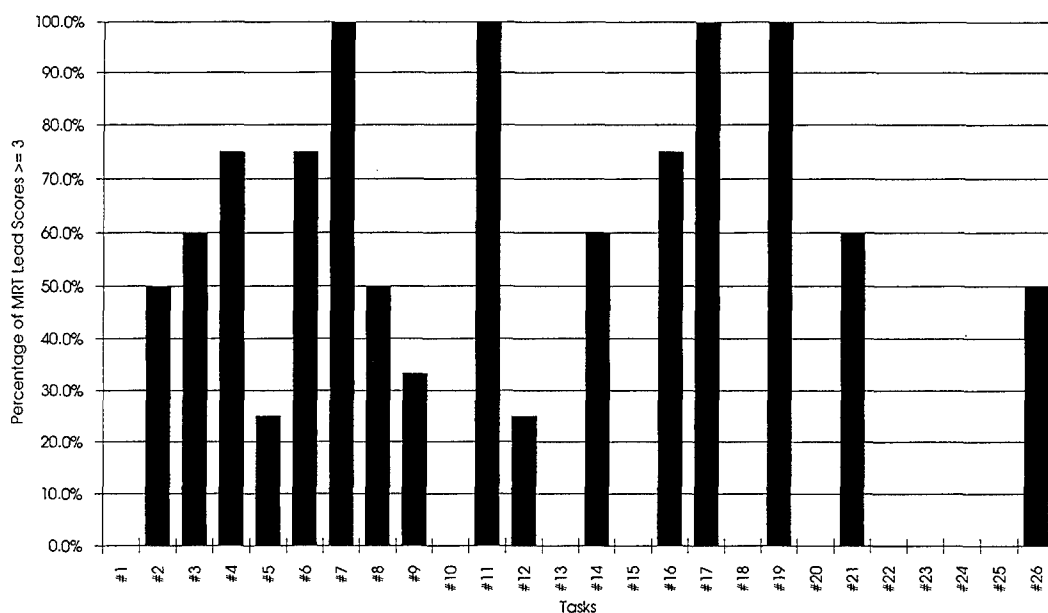
Figure 3-7.   Percentage of All Pilot Training Capability Ratings of Three or
More for Flight Lead Mission Readiness Training on
Two-Channel AOI (Site 1).

3.1.2.1.2.2 Results and Discussion for Site 2: Display for Advanced Research and Training (DART) and Mini-Display for Advanced Research and Training (Mini-DART).

3.1.2.1.2.2.1 Twenty-four tasks flown by the evaluation pilots were rated for the potential of the visual system to support mission readiness training for wingman (see Figure 3-8.). The results show that ten tasks received a rating of three or greater for at least 80% of the task ratings by the evaluation pilots. Tasks that met the criterion were:

Task #4	Combat Descent (100%)
Task #6	Single Ship Low Level (80%)
Task #7	Visual Low Level Navigate to Initial Point (100%)
Task #10	Detect Electronic Threats (100%)
Task #13	Tactical Instruments Cross Check (100%)
Task #16	Low Altitude Weapon Delivery (LAS, LALD, LAB, VLD) (80%)
Task #19	Target Reattack (80%)
Task #21	Low Altitude Intercept (80%)
Task #22	AIM-9 Employment (100%)
Task #23	Low Altitude Air-to-Air Gun Employment (100%)
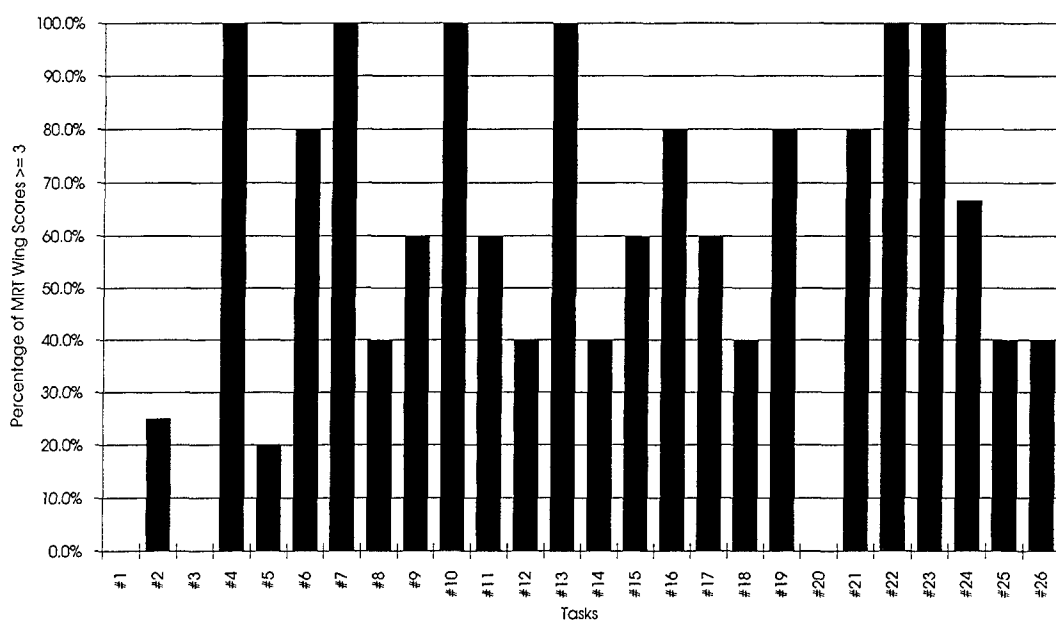
Figure 3-8. Percentage of All Pilot Training Capability Ratings of Three or More for Pilot Wingman Mission Readiness Training on the DART (Site 2).

3.1.2.1.2.2.2 The twenty-four tasks flown by the evaluation pilots were rated for the potential of the visual system to support mission readiness training for flight leads (see Figure 3-9.). The results show that eleven tasks received a rating of three or greater for at least 80% of the task ratings. Tasks that met the criterion were as follows:

Task #4	Combat Descent (100%)
Task #7	Visual Low Level Navigate to Initial Point (100%)
Task #10	Detect Electronic Threats (100%)
Task #13	Tactical Instruments Cross Check (100%)
Task #16	Low Altitude Weapon Delivery (LAS, LALD, LAB, VLD) (100%)
Task #17	High Altitude Weapon Delivery (HAS, HD, DB, DTOS) (100%)
Task #19	Target Reattack (100%)
Task #21	Low Altitude Intercept (100%)
Task #22	AIM-9 Employment (100%)
Task #23	Low Altitude Air-to-Air Gun Employment (100%)
Task #25	Wingman Responsibilities (100%)

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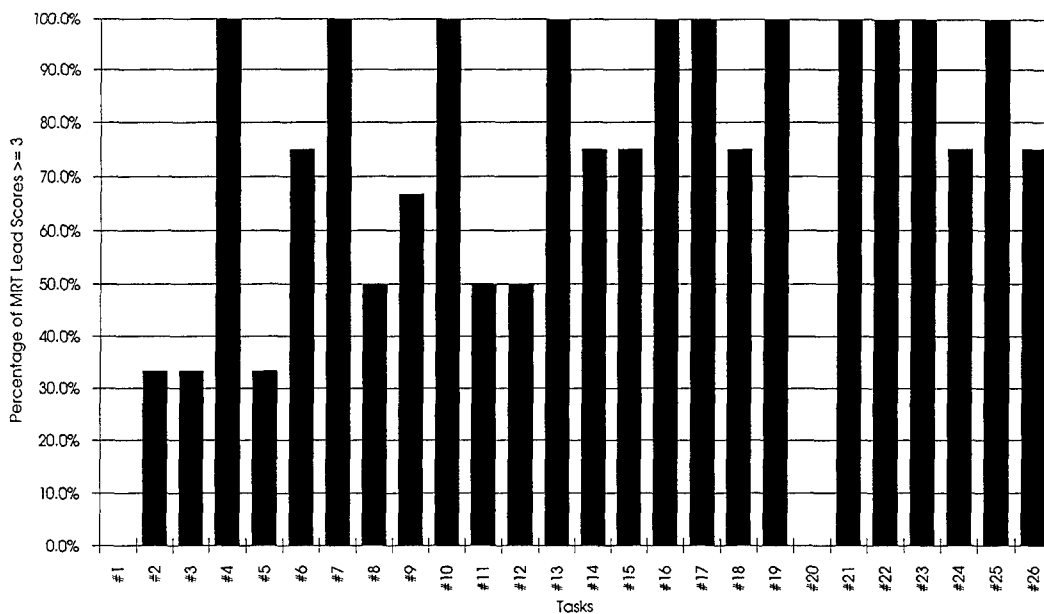
Figure 3-9. Percentage of All Pilot Training Capability Ratings of Three or More for Pilot Flight Lead Mission Readiness Training on the DART (Site 2).

3.1.2.1.2.2.3 The Mini-DART was not rated for wingman or flight lead mission readiness training capability due to the similarity of technology for the DART and Mini-DART.

3.1.2.1.2.3 Results and Discussion for Site 3: Fiber Optic Helmet Mounted Display (FOHMD).

3.1.2.1.2.3.1 Twenty-four tasks flown by the evaluation pilots at Site 3 were rated for the potential of the visual system to support mission readiness training for wingman (see Figure 3-10.). The results show that eight tasks received a rating of three or greater for at least 80% of the task ratings by the evaluation pilots. The tasks that met the criterion were:

Task #4   Combat Descent (100%)
Task #11   Terrain Masking (direct/indirect) (80%)
Task #16   Low Altitude Weapon Delivery (LAS, LALD, LAB, VLD) (80%)
Task #17   High Altitude Weapon Delivery (HAS, HD, DB, DTOS) ((80%)
Task #19   Target Reattack (80%)
Task #20   Aircraft Battle Damage Check (100)
Task #22   AIM-9 Employment (100%)
Task #23   Low Altitude Air-to-Air-Gun Employment (100%)

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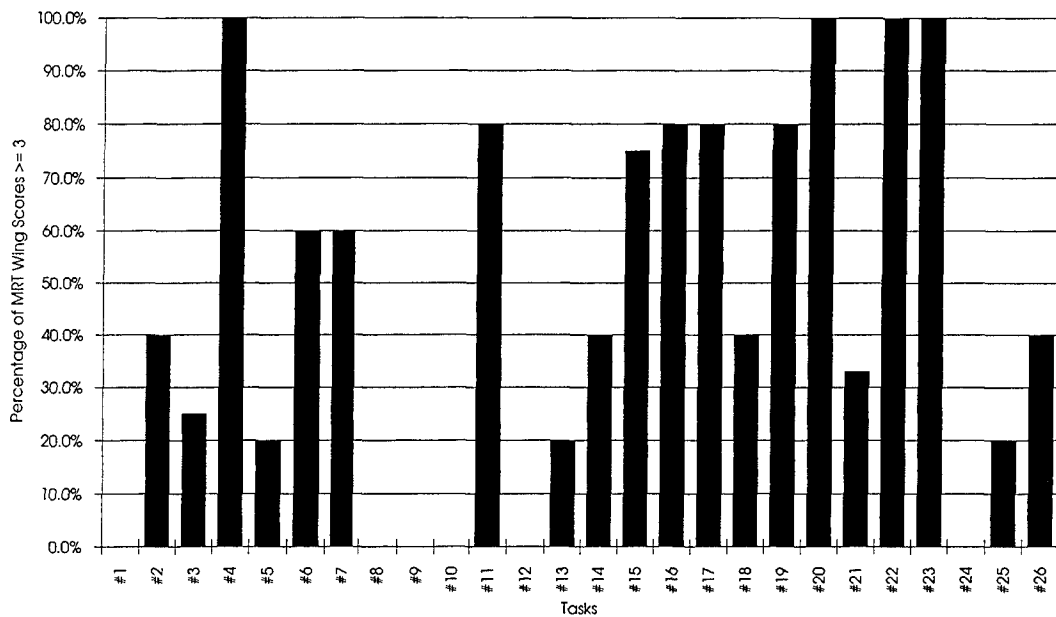
Figure 3-10.   Percentage of All Pilot Training Capability Ratings of Three
or More for Pilot Wingman Mission Readiness Training on
FOHMD (Site 3).

3.1.2.1.2.3.2 The twenty-four tasks flown by the evaluation pilots were rated for the
potential of the visual system to support mission readiness training for flight leads (see
Figure 3-11.). The results show that eight tasks received a rating of three or greater for at
least 80% of the task ratings by the evaluation pilots. The tasks that met the criterion
were as follows:

Task #4	Combat Descent (100%)
Task #11	Terrain Masking (direct/indirect) (100%)
Task #15	Coordinated Tactical Attack (100%)
Task #16	Low Altitude Weapon Delivery (LAS, LALD, LAB, VLD) (100%)
Task #17	High Altitude Weapon Delivery (HAS, HD, DB, DTOS) (100%)
Task #19	Target Reattack (100%)
Task #22	AIM-9 Employment (100%)
Task #23	Low Altitude Air-to-Air Gun Employment (100%)

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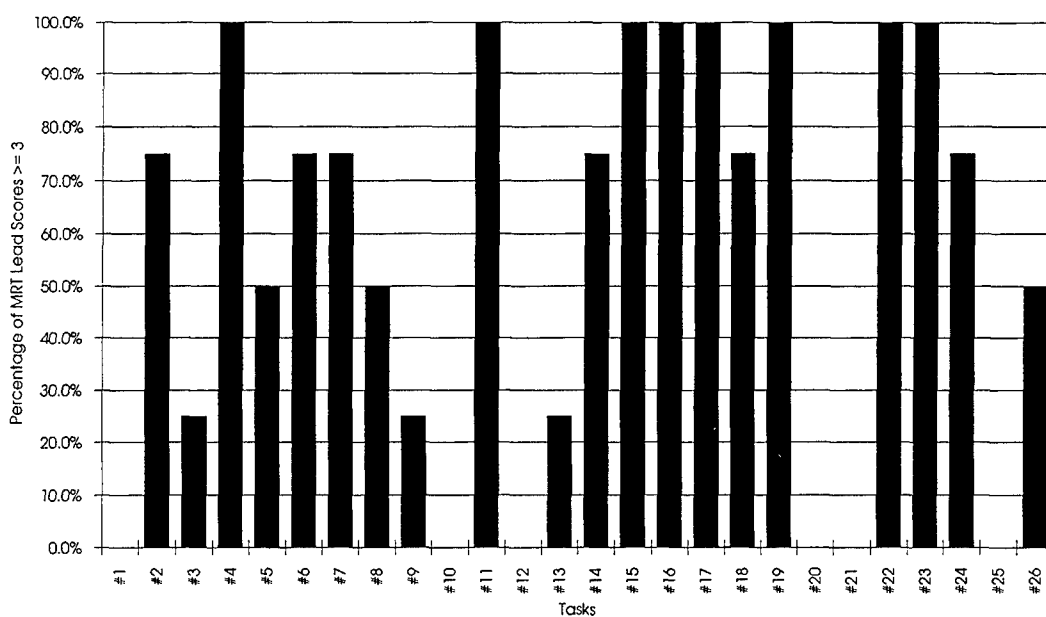
Figure 3-11. Percentage of All Pilot Training Capability Ratings of Three or More for Pilot Flight Lead Mission Readiness Training on FOHMD (Site 3).

3.1.2.1.2.3.3 Twenty-two tasks flown by the WSOs were rated for the potential of the visual system to support mission readiness training for WSO wingman (see Figure 3-12.). The results show that eight tasks received a rating of three or greater for at least 80% of the task ratings by the WSOs. Tasks that met the criterion were as follows:

Task #4   Intraflight Coordination/Communication (100%)
Task #5   Intercockpit Coordination/Communication (100%)
Task #10   Coordinated Tactical Attack (100%)
Task #14   Target Reattack (100%)
Task #15   Aircraft Battle Damage Check (100%)
Task #17   Situational Awareness of Tactical Situations (100%)
Task #20   Direct Target Attack/Reattack (100%)
Task #22   Direct Egress (100%)
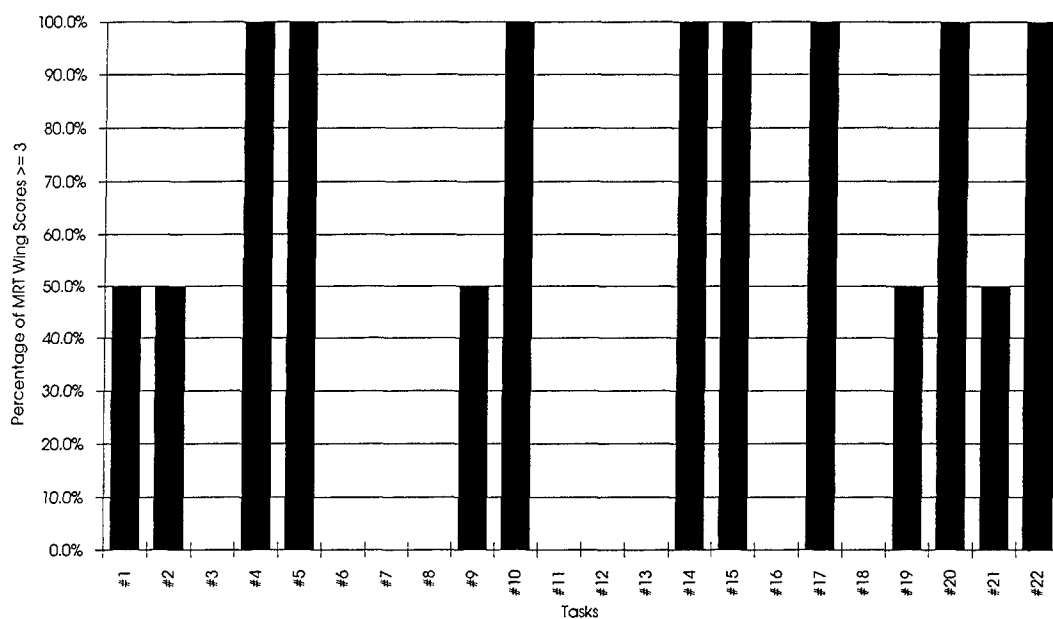
Figure 3-12.   Percentage of All WSO Training Capability Ratings of Three
or More for WSO Wingman Mission Readiness Training on
FOHMD (Site 3)

3.1.2.1.2.3.4 The twenty-two tasks flown by the WSOs were rated for the potential of the
visual system to support mission readiness training for WSO flight leads (see Figure 3-
13.). The results show that nine tasks received a rating of three or greater for at least 80%
of the task ratings by the WSOs. The tasks that met the criterion were:

|	
Task #1	Single Ship Low Level (100%)
Task #4	Intraflight Coordination/Communication (100%)
Task #5	Intercockpit Coordination/Communication (100%)
Task #10	Coordinated Tactical Attack (100%)
Task #14	Target Reattack (100%)
Task #15	Aircraft Battle Damage Check (100%)
Task #17	Situational Awareness of Tactical Situations (100%)
Task #20	Direct Target Attack/Reattack (100%)
Task #22	Direct Egress (100%)

Figure 3-13.   Percentage of All WSO Training Capability Ratings of Three
or More for WSO Flight Lead Mission Readiness Training
on FOHMD (Site 3).

3.1.2.2 Subobjective 2-2. Evaluate the capability of the selected image display
technologies to support continuation training for wingman and flight lead.

3.1.2.2.1 Measures and Criteria. The measures and criteria for training effectiveness are
discussed in paragraph 2.2.1.

3.1.2.2.2 Results and Discussion. Data for this objective was obtained at the conclusion
of the final evaluation mission. The questionnaire requested the evaluator to rate the
potential of the visual system to support operational continuation training. Each of the
tasks flown in the three evaluation missions was evaluated. The intent was to obtain an
overall assessment of the evaluators across all missions. The assessment requested the
evaluators to base their ratings upon their own experience in training students and their
past operational experience. It should be recognized that this rating was a single rating
reflecting the evaluator's assessment of the potential of the visual system to support
continuation training. Therefore, the results may be expected to differ slightly from the
results in Objective 1.

3.1.2.2.2.1 Results and Discussion for Site 1: Two-Channel Area of Interest (AOI) Dome.

3.1.2.2.2.1.1 The eighteen tasks flown by the evaluation pilots were rated for the potential of the visual system to support continuation training for wingman (see Figure 3-14.). The results show that three tasks received a rating of three or greater for at least 80% of the task ratings. The tasks that met the criterion were:

Task #11   Terrain Masking (direct/indirect) (86%)
Task #17   High Altitude Weapon Delivery (HAS, HD, DB, DTOS) (100%)
Task #19   Target Reattack (100%)
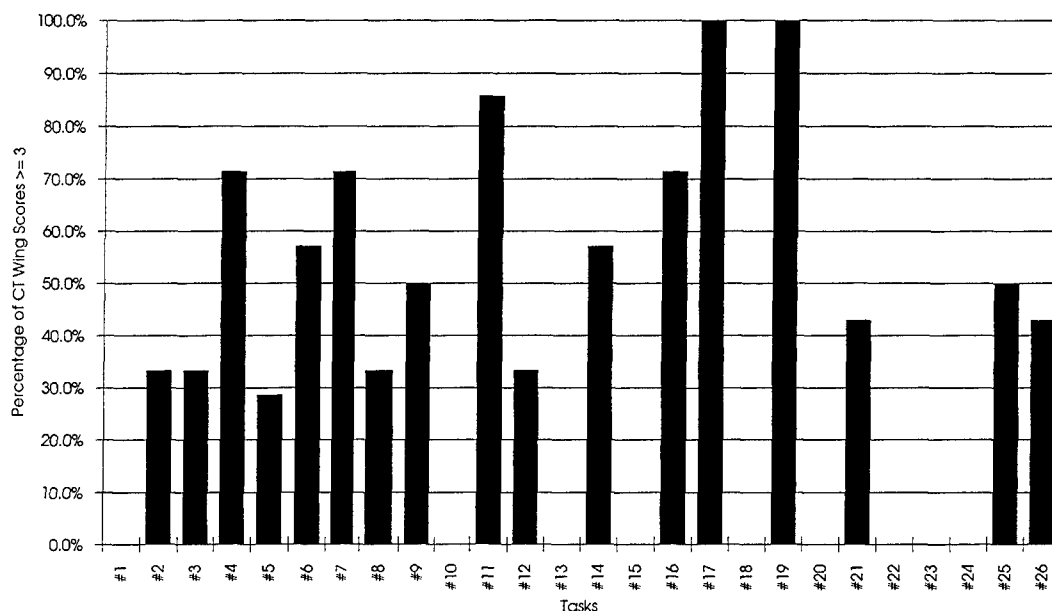
Figure 3-14.   Percentage of All Pilot Training Capability Ratings of Three
or More for Wingman Continuation Training on
Two-Channel AOI (Site 1).

3.1.2.2.2.1.2 Eighteen tasks flown by the evaluation pilots were rated for the potential of the visual system to support continuation training for flight leads (see Figure 3-15.). The results show that five tasks received a rating of three or greater for at least 80% of the task ratings. Tasks that met the criterion were:

Task #4   Combat Descent (86%)
Task #7   Visual Low Level Navigate to Initial Point (86%)
Task #11   Terrain Masking (direct/indirect) (100%)
Task #17   High Altitude Weapon Delivery (HAS, HD, DB, DTOS) (100%)
Task #19   Target Reattack (100%)

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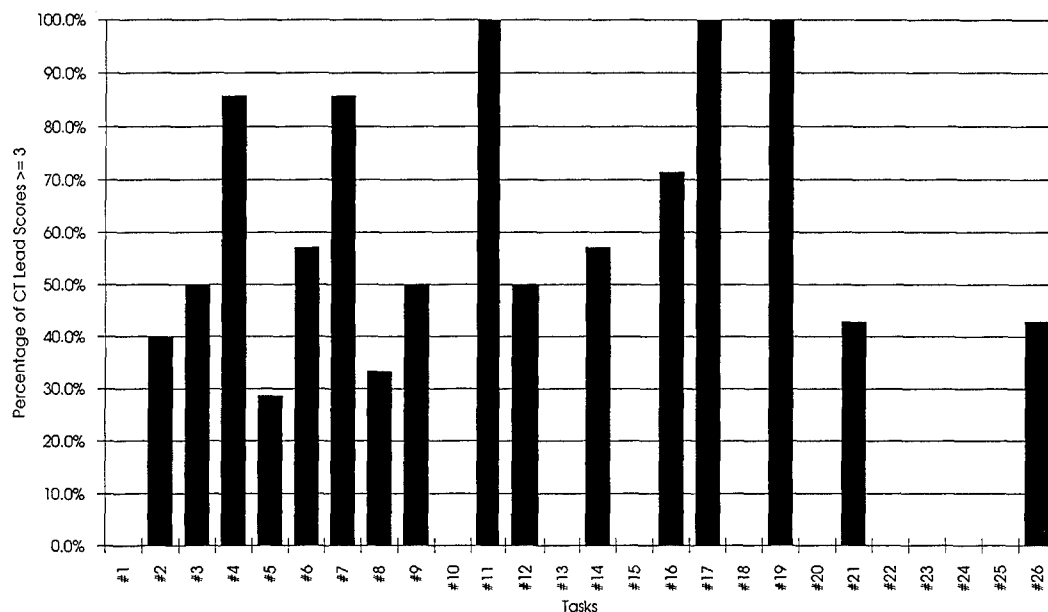
Figure 3-15. Percentage of All Pilot Training Capability Ratings of Three
or More for Flight Lead Continuation Training on
Two-Channel AOI (Site 1).

**3.1.2.2.2.2 Results and Discussion for Site 2: Display for Advanced Research and
Training (DART) and Mini-Display for Advanced Research and
Training (Mini-DART).**

3.1.2.2.2.2.1 Twenty-four tasks flown by the evaluation pilots were rated for the potential
of the visual system to support continuation training for wingman (see Figure 3-16.). The
results show that eleven tasks received a rating of three or greater for at least 80% of the
task ratings by the evaluation pilots. Tasks that met the criterion were:

|	
Task #4	Combat Descent (100%)
Task #6	Single Ship Low Level (80%)
Task #7	Visual Low Level Navigate to Initial Point (100%)
Task #9	Detect Visual Threats (80%)
Task #10	Detect Electronic Threats (100%)
Task #13	Tactical Instruments Cross Check (100%)
Task #15	Coordinated Tactical Attack (80%)
Task #16	Low Altitude Weapon Delivery (LAS, LALD, LAB, VLD) (100%)
Task #17	High Altitude Weapon Delivery (HAS, HD, DB, DTOS) (80%)
Task #19	Target Reattack (100%)
Task #21	Low Altitude Intercept (100%)
Task #22	AIM-9 Employment (100%)
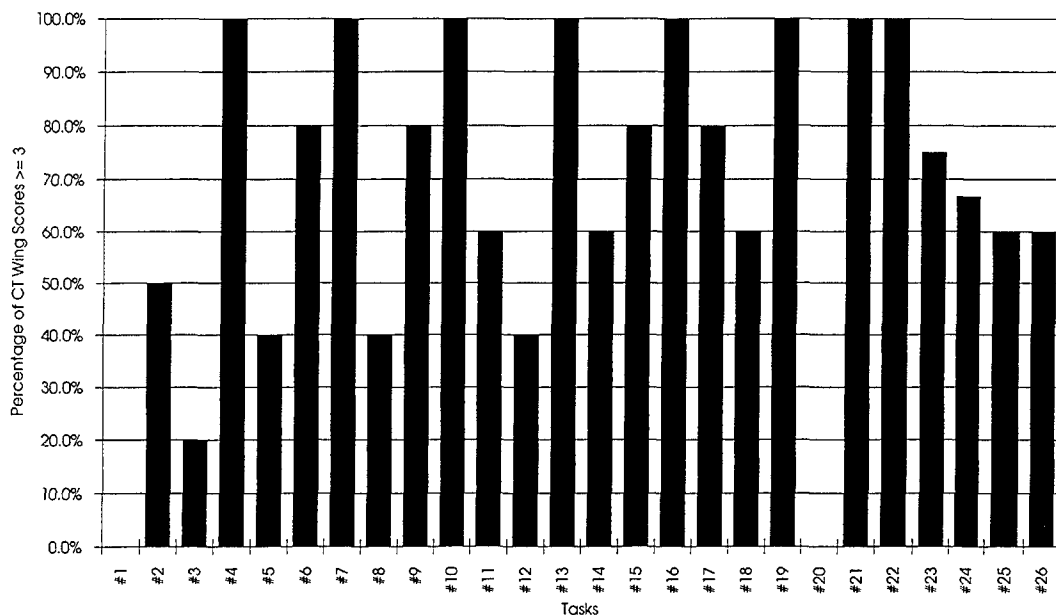
Figure 3-16. Percentage of All Pilot Training Capability Ratings of Three or More for Wingman Continuation Training on the DART (Site 2).

3.1.2.2.2.2.2 Twenty-four tasks flown by the evaluation pilots were rated for the potential of the visual system to support continuation training for flight leads (see Figure 3-17.). The results show that fourteen tasks received a rating of three or greater for at least 80% of the task ratings by the evaluation pilots. Tasks that met the criterion were:

|	
Task #4	Combat Descent (100%)
Task #6	Single Ship Low Level (80%)
Task #7	Visual Low Level Navigate to Initial Point (100%)
Task #9	Detect Visual Threats (80%)
Task #10	Detect Electronic Threats (100%)
Task #13	Tactical Instruments Cross Check (100%)
Task #14	Visual Target Acquisition/Identification (80%)
Task #15	Coordinated Tactical Attack (80%)
Task #16	Low Altitude Weapon Delivery (LAS, LALD, LAB, VLD) (100%)
Task #17	High Altitude Weapon Delivery (HAS, HD, DB, DTOS) (80%)
Task #18	Reform After Tactical Attack (80%)
Task #19	Target Reattack (100%)
Task #21	Low Altitude Intercept (100%)
Task #22	AIM-9 Employment (100%)
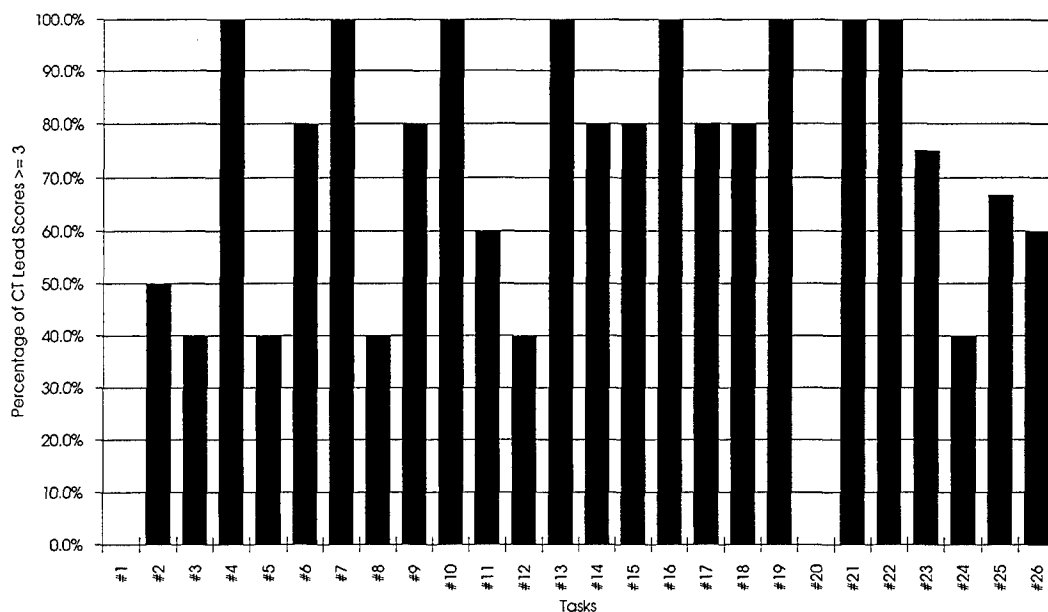
Figure 3-17. Percentage of All Pilot Training Capability Ratings of Three
or More for Flight Lead Continuation Training on the DART
(Site 2).

3.1.2.2.2.3 The Mini-DART was not rated for Wingman and Flight Lead continuation
training capability due to the similarity of the technology for the DART and the Mini-
DART.

3.1.2.2.2.3 Results and Discussion for Site 3: Fiber Optic Helmet Mounted Display (FOHMD).

3.1.2.2.2.3.1 Twenty-four tasks flown by the evaluation pilots were rated for the potential
of the visual system to support continuation training for wingman (see Figure 3-18.). The
results show that eight tasks received a rating of three or greater for at least 80% of the
task ratings by the evaluation pilots. Tasks that met the criterion were:

|	
Task #4	Combat Descent (100%)
Task #6	Single Ship Low Level (80%)
Task #11	Terrain Masking (direct/indirect) (80%)
Task #16	Low Altitude Weapon Delivery (LAS, LALD, LAB, VLD) (80%)
Task #17	High Altitude Weapon Delivery (HAS, HD, DB, DTOS) (100%)
Task #20	Aircraft Battle Damage Check (100%)
Task #22	AIM-9 Employment (100%)
Task #23	Low Altitude Air-to-Air Gun Employment (100%)

Figure 3-18.   Percentage of All Pilot Training Capability Ratings of Three
or More for Pilot Wingman Continuation Training on
FOHMD (Site 3).

3.1.2.2.2.3.2 Twenty-four tasks flown by the evaluation pilots were rated for the potential
of the visual system to support continuation training for flight leads (see Figure 3-19.).
The results show that eight tasks received a rating of three or greater for at least 80% of
the task ratings by the evaluation pilots. Tasks that met the criterion were:

Task #4	Combat Descent (100%)
Task #6	Single Ship Low Level (80%)
Task #11	Terrain Masking (direct/indirect) (80%)
Task #16	Low Altitude Weapon Delivery (LAS, LALD, LAB, VLD) (80%)
Task #17	High Altitude Weapon Delivery (HAS, HD, DB, DTOS) (100%)
Task #20	Aircraft Battle Damage Check (100%)
Task #22	AIM-9 Employment (100%)
Task #23	Low Altitude Air-to-Air Gun Employment (100%)

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Figure 3-19.   Percentage of All Pilot Training Capability Ratings of Three
or More for Pilot Flight Lead Continuation Training on
FOHMD (Site 3).

3.1.2.2.2.3.3 The twenty-two tasks flown by the WSOs were rated for the potential of the
visual system to support continuation training for WSO wingman (see Figure 3-20.). The
results show that eight tasks received a rating of three or greater for at least 80% of the
task ratings by WSOs. Tasks that met the criterion were:

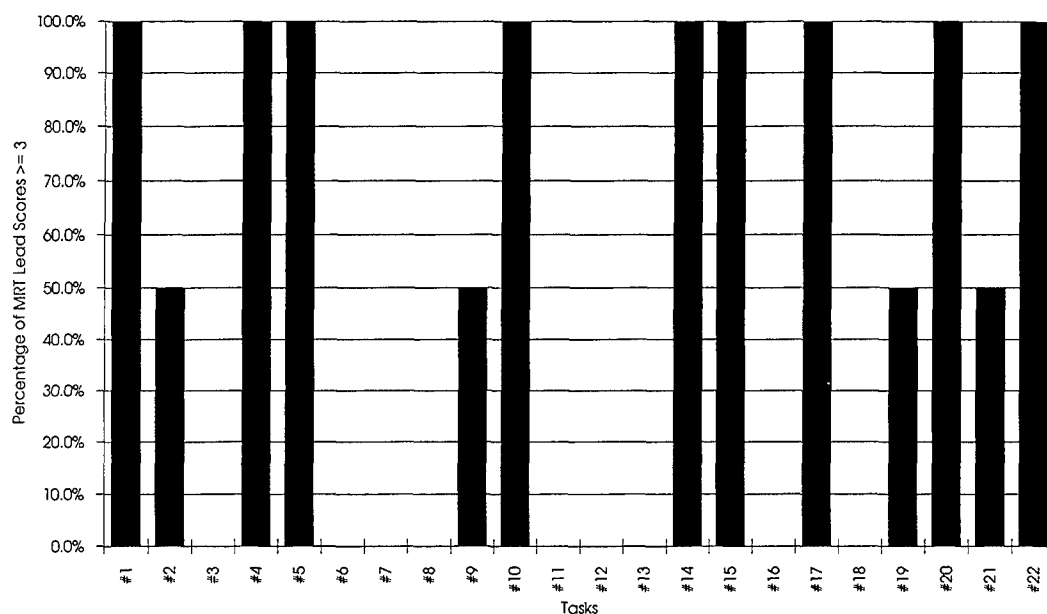|	
Task #4	Intraflight Coordination/Communication (100%)
Task #5	Intercockpit Coordination/Communication (100%)
Task #10	Coordinated Tactical Attack (100%)
Task #14	Target Reattack (100%)
Task #15	Aircraft Battle Damage Check (100%)
Task #17	Situational Awareness of Tactical Situations (100%)
Task #20	Direct Target Attack/Reattack (100%)
Task #22	Direct Egress (100%)
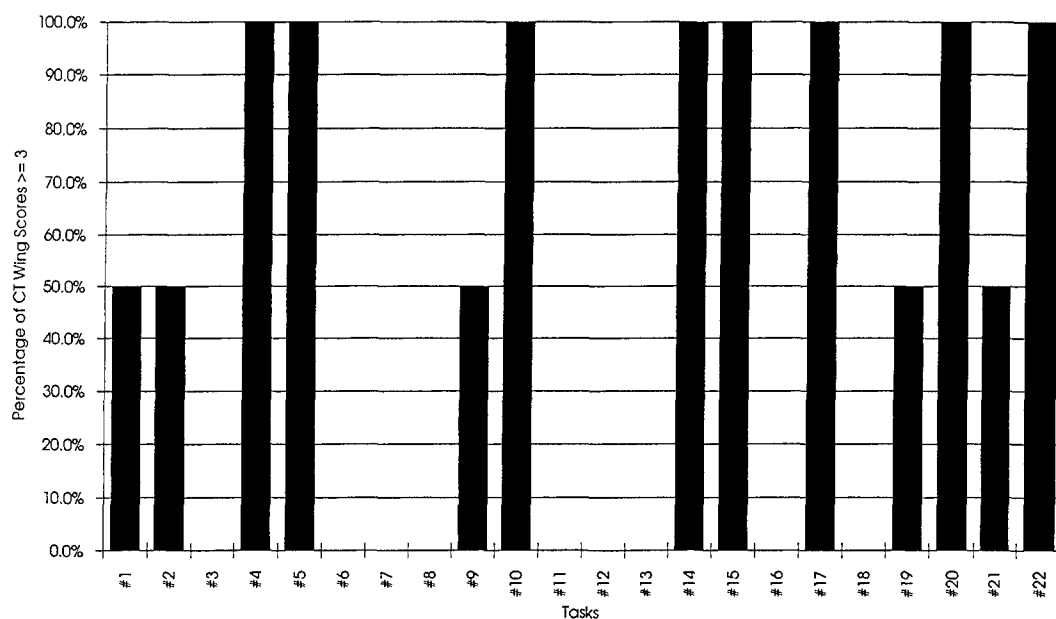
Figure 3-20. Percentage of All WSO Training Capability Ratings of Three or More for WSO Wingman Continuation Training on FOHMD (Site 3).

3.1.2.2.2.3.4 The twenty-two tasks flown by the WSOs were rated for the potential of the visual system to support continuation training for WSO flight leads (see Figure 3-21.). The results show that nine tasks received a rating of three or greater for at least 80% of the task ratings by WSOs. Tasks that met the criterion were:

|	
Task #1	Single Ship Low Level (100%)
Task #4	Intraflight Coordination/Communication (100%)
Task #5	Intercockpit Coordination/Communication (100%)
Task #10	Coordinated Tactical Attack (100%)
Task #14	Target Reattack (100%)
Task #15	Aircraft Battle Damage Check (100%)
Task #17	Situational Awareness of Tactical Situations (100%)
Task #20	Direct Target Attack/Reattack (100%)
Task #22	Direct Egress (100%)

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Figure 3-21. Percentage of All WSO Training Capability Ratings of Three or More for WSO Flight Lead Continuation Training on FOHMD (Site 3).

3.1.3 <u>Objective 3.</u> Baseline and document the engineering attributes for each simulator configuration.

3.1.3.1 <u>Measures and Criteria</u>. No criteria were established for each visual system configuration. The objective only necessitated the collection and documentation of system performance data for each visual system configuration. If system performance data were unavailable, system performance was measured using test procedures identified in AFGS-87241, paragraph 4.7.

3.1.3.2 <u>Results and Discussion</u>. Annex E of this report is a detailed description of the visual system performance attributes.

3.1.3.2.1 **Results and Discussion for Site 1: Two-Channel Area of Interest (AOI) Dome**. The visual system evaluated at Evans and Sutherland Corporation consisted of a dome display with two head tracked projectors. One projector produced a low resolution background image and the second produced a high resolution area of interest (AOI) image optically inset into the background scene.

3.1.3.2.1.1 <u>Display</u>. The dome display provided a total FOV of 123 degrees by 99 degrees, with the AOI occupying the center 42 degrees by 32 degrees. This FOV followed the pilot's head position to remain in the forward line-of-sight constantly. The projector's were capable of slewing up to 20 radians per second, with accelerations of 40 radians per second per second to follow the pilot's movements. The projectors and dome

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together produced full color imagery with brightness of 5 foot-Lamberts and 15 to 1 contrast ratio. The resolution of the background imagery was 20.6 arc minutes per line pair and of the AOI imagery was 6.9 arc minutes per line pair. The insertion of the AOI imagery was accomplished by optically filtering the high resolution imagery across an 1 to 1.5 degree circular blend region to the level of the low resolution imagery.

3.1.3.2.1.2 Image Generator. The out-the-window imagery was generated by a two channel ESIG-3000 image generator (IG). The IG created 4000 polygons for displaying the background imagery, and 2000 polygons for the AOI imagery. The lights (non-calligraphic) created are traded off with polygons at 2.5 lights to 1 polygon. The advanced texture capabilities of the IG are photo, intensity modulation, color modulation, and transparency texture. Four texture maps can be applied to each polygon. Each texture map can be offset, moving, continuous, projected, and blended. The IG stores up to 1024 texture maps on-line at any one time. The IG is range buffered, so the number of occultation levels is limited only by the number of pixel writes. The IG generates a scene 60 times a second, for a transport delay of 3.5 fields, or 58.3 milliseconds. During overload conditions this delay will lengthen as the system takes longer to generate the scene. Weather and environmental effects provided by the IG include day/night/dusk ambient light with continuous time of day, visibility adjustments from 0 to 500 miles (includes fog effects), two independent cloud decks with scud, three levels of storm intensity with lightning flashes and visibility degradation, and sun angle shading. Special effects provided by the IG include animations, different light effects, and different surface shading effects.

3.1.3.2.1.3 Data Base. The data base was of the Hunter-Liggett area in California, and was the Standard Interchange Format (SIF) version created for use as a distributed interactive simulation demonstration data base. The data base was not correlated to the real world, so the lead evaluation pilot created route maps for each segment of the mission. The size of the data base was 120 nautical miles (NM) by 90 NM, with a 10 KM by 30 KM airfield area contained within a 60 NM by 60 NM low altitude area. The scene density for the low altitude area was 2500 - 3000 polygons, with 1200 for terrain, 1500 for features, and 300 for moving models. For the remainder of the data base the scene density was 1250-1500 polygons, with 500 for terrain and the rest for moving models. The displayed terrain transitioned through five levels of detail. Features and models transitioned through 3 to 5 levels of detail, depending on the complexity. Examples of moving models included tanks, F-16, MiG-29, Hind Helicopter, and Sidewinder missile.

3.1.3.2.1.4 Tracker. A magnetic transmitter mounted on the pilot's helmet and a sensor in the dome tracks the pilot's head and sends signals to slew the projectors. By tracking the pilot's head position, the imagery, both background and AOI, remains in front of the pilot's line-of-sight. The accuracy of the tracker was 0.1 degree for the total FOV. This means the imagery was correctly positioned to within +/- 0.1 degree whenever the pilot moved his head. The sensor can be located anywhere within the dome, but the larger the

separation from the helmet transmitter, the less accurate the positioning. For this evaluation, the location was specified to be within three feet.

3.1.3.2.2 Results and Discussion for Site 2: Display for Advanced Research and Training (DART) and Site #2B: Mini-DART.

The DART visual system evaluated at Armstrong Lab, Gateway Airport AZ consisted of a nine channel rear projection flat screen wrap-around display. The Mini-DART visual system evaluated at Armstrong Lab, Williams Gateway Airport AZ also consisted of an eight channel rear projection flat screen wrap-around display. The Mini-DART had a smaller footprint through the use of mirrors to bend the optical path of the projectors. Other differences can be distinguished in the following paragraphs.

3.1.3.2.2.1 <u>Display (DART)</u>. The display provided a total FOV of 360 degrees horizontal by 110 degrees vertical. The rear projectors and screens together produced full color imagery with brightness of 15 foot-Lamberts and 50 to 1 contrast ratio. The resolution of the imagery was 9.5 arc minutes per line pair. The flat screens produced a real image located 3.1 feet from the pilot's eyepoint. A HUD was superimposed on the front screen by a separate projector.

3.1.3.2.2.1.1 <u>Display (Mini-DART)</u>. The display provided a total FOV of 360 degrees horizontal by 130 degrees vertical. The rear projectors and screens together produced full color imagery with a brightness of 50 foot-Lamberts for the front screen, 15 foot-Lamberts for the remaining screens, and a 50 to 1 contrast ratio for all screens. The resolution of the imagery was 5.07 arc minutes per line pair for the front screen and 9.75 arc minutes per line pair for the remaining screens. The flat screens produced a real image located two feet from the pilot's eyepoint. A HUD was electronically mixed and projected with the front screen imagery.

3.1.3.2.2.2 <u>Image Generator</u>. The out-the-window imagery was generated by a ten channel Compu-Scene IV IG prototype. The IG created 8000 polygons for displaying the imagery. The lights (non-calligraphic) created are traded off with polygons at 2.5 lights to 1 polygon. The texture capabilities of the IG are cell and stripe texture. The IG stores up to 16 texture maps (256 X 256 texels) on-line at any one time. The number of occultation levels is 4000. The IG generates a scene 60 times a second, for a transport delay of 60 milliseconds. Weather and environmental effects provided by the IG include day/night/dusk ambient light, visibility adjustments from 0 to 16,900 feet (includes fog effects), one independent cloud deck with scud, and fixed sun angle shading. Special effects provided by the IG include 16 weapon effects, and different surface shading effects.

3.1.3.2.2.3 <u>Data Base</u>. The data bases were of Washington State and Germany. The data bases were correlated to the real world. The sizes of the data bases were 5700 SQ NM for Washington state with 1400 SQ NM developed to more than just terrain, and approximately 10,200 SQ NM for Germany with an airfield area of approximately 45 SQ NM. The scene densities for both data bases are unknown. Features and models

transitioned through three levels of detail. Examples of moving models include tanks, F-16, MiG-27, Su-27, and F-15 aircraft.

3.1.3.2.3 Results and Discussion for Site #3: Fiber Optic Helmet Mounted Display (FOHMD). The visual system evaluated at Stolberg, GE, consisted of a three channel head tracked helmet mounted display (HMD), with an eye tracked inset.

3.1.3.2.3.1 <u>Display</u>. The display provided a instantaneous FOV of 127 degrees horizontal by 66 degrees vertical for the background, and 24 degrees horizontal by 18 degrees vertical for the inset. The HMD could be used to look anywhere within the pilot's head movement envelope, so the total FOV was effectively anywhere the pilot could look. The display system consisted of light valve projectors, fiber optic cables for image transmission, and pancake window optics for viewing the imagery, which together produced full color imagery with a brightness of 30 foot-Lamberts and 9 to 1 contrast ratio (estimated). Each eye had a separate display system consisting of background display optics and AOI display optics. The resolution of the imagery was three arc minutes per line pair for the inset and 5 arc minutes per line pair for the background. The pancake window optics produced an image collimated at greater than 10 meters from the pilot's eyepoint. The HUD was viewed normally through the pancake window optics, which is 10% transmissive.

3.1.3.2.3.2 <u>Image Generator</u>. The out-the-window imagery was generated by a three channel ESIG-1000 IG. The IG created independent background imagery for each eye using two channels and common AOI imagery with the third channel. The IG created 2000 polygons for displaying the imagery in the inset and 2400 polygons for the background. The lights (non-calligraphic) created are traded off with polygons at 3 lights to 1 polygon. The texture capabilities of the IG are full color, fixed, moving, and photographic texture. The IG stores up to 128 texture maps (128 X 128 texture elements) on-line at any one time. The number of occultation levels is equal to the number of polygons (range buffering). The IG generates a scene 60 times a second, for a transport delay of 66.67 milliseconds. Weather and environmental effects provided by the IG include day/night/dusk ambient light, visibility adjustments from 0 to 20 nautical miles in 1 foot increments, fog effects from 0 to 10 nautical miles in 1 foot increments, cloud deck upto 44,000 feet with scud, and dynamic sun angle shading. Special effects provided by the IG include weapon explosions, tracers, IR flares, and smooth surface shading effects.

3.1.3.2.3.3 <u>Data Base</u>. The data base was of Germany (50 to 52 degrees north latitude and 8 to 10 degrees east longitude), with the Lechfeld and Neuberg airfields and the Muensingen bomb range. The data bases were correlated to the real world. The size of the data base was 30,000 SQ KM with two enhanced regions of approximately 10 by 30 NM for low altitude flying. The scene densities are; for terrain, 1.7 polygons per SQ NM at low level of detail (LOD), 6.7 polygons per SQ NM at medium LOD, and 26.7 polygons per SQ NM at high LOD; for culture, 16 polygons per SQ NM at low LOD and 600 polygons per SQ NM at high LOD. Examples of moving models include MRCA,

MiG-23, MiG-29, F-4, SA-8, T-80, and ZSU-23/4. Other models include the Fishbed, Backfire, T-72, F-15, F-16, CH-53, B0105, HIND, M-1, M-2, SA-9, ZSU-57, and BMP.

3.2 ADDITIONAL FINDINGS

3.2.1 Additional Findings for Site 1 (Two-Channel AOI Dome).

3.2.1.1 Additional FOV and Resolution. The evaluation pilots indicated that they believed a wider field of view for both the inset AOI and the background scene was required. Most pilots reported that seeing the black edges of the background scene was very distracting. They indicated the resolution of the background scene needs to be improved so they can pick up more visual cues with their peripheral vision. Pilots also mentioned a brighter display would have helped them to acquire visual information faster. On the basis of discussions with the site engineering staff, planned improvements to the visual system will include a wider field of view and a higher brightness projection system.

3.2.1.2 Target Projector. The pilots indicated the target projector produced a green image that was too bright. Pilots indicated that at longer ranges, the contrast of a real world aircraft is not as good as the current simulated aircraft. The evaluation pilots pointed out that as the range of a real aircraft increases, the aircraft becomes black in color when viewed against the horizon and sky. Also, details on the aircraft such as markings, control surfaces, etc., cannot be seen as range increases. In fact, loss of these visual cues is one of the major cues that give pilots their estimates of range. Object size relative brightness and resolvable characteristics are other important cues for range determination.

3.2.1.3 Generic Fighter Cockpit. Evaluation pilots indicated the lack of a fighter cockpit and HUD adversely impacted the results of this study. The generic fighter cockpit at Site 1 did not permit the normal instrument cross check. It did not have a weapons system radar or RWR. Most importantly, it was missing a HUD. Today's pilots rely heavily upon the HUD. Indeed, many pilots report they rarely look into the cockpit except for quick glances at the attack radar or RWR. In this evaluation, many of the tactical tasks were rated low on training capability due in large part to the lack of an adequate fighter cockpit.

3.2.1.4 Image Generator and Data Base. (Size and optimization for air to surface) The pilots reported the data base needed to have more cultural and geographic detail available. The pilots pointed out that at low altitude they can see numerous features such as people, vegetation, trees, vehicles, animals, etc.; and all of these objects give them a sense of altitude. The image generator provided texturing. However, the majority of the pilots reported difficulty in judging their altitude over the green forested areas. Most reported this area was too smooth and looked more like a lawn rather than the top of a forested area. They also noted the texturing was always the same regardless of altitude or range when in the real world texturing may be fuzzy or indistinct at long ranges and high

altitudes but begins to become sharp and focused as range and altitude decrease. The team consensus was that multiple levels of texturing are needed to make visual scenes like the real world. The evaluation team was provided a demonstration of the ESIG 4000 at the completion of the evaluation. The pilots indicated that with the improvements planned for the two-channel display system, a higher-detail data base, multiple levels of texturing, and a higher capability image generator would make it useful to reevaluate the training capability of the system.

3.2.1.5 Head-tracking. Head-tracking forced the pilots to use exaggerated head movements to visually acquire a target or visual object. Head-tracking required the pilots to steer the AOI to the area they wanted to see. This resulted not only in changes to normal visual habit patterns but also caused them to fixate on the visual object longer than normal. Pilots commented that eye tracking is needed to provide the pilot with high resolution AOI without having to move their head. Pilots move their eyes to their physiological limits to pick up objects of interest, rather than turn their heads to directly look at the object. Their eyes tend to move rapidly from one search area to the next interspersed with quick glances to their HUD or cockpit instrumentation to pick up additional information.

3.2.1.6 Availability. The evaluation did not focus on Operational Suitability issues. Data to address these issues was not formally collected. However, the system had an outstanding availability rate during the evaluation. The system was used operationally 8-14 hours per day with little additional time for maintenance. During this time only a single mission was lost due to the system being down; this mission was quickly made up and no further down time was experienced.

3.2.2 Additional Findings for Site 2 (DART and Mini-DART).

3.2.2.1 Resolution. Pilots indicated the resolution of the DART and Mini-DART was not adequate at ranges outside 3000 to 5000 feet. Lack of adequate resolution impacted their ratings on tasks involving formation flight, threat identification, and target acquisition .

3.2.2.2 Brightness. Pilots commented that the brightness for both the DART and Mini-DART was very good. High display brightness coupled with full field of view were significant enhancements of this display technology.

3.2.2.3 Image Generator and Data Base. Several of the pilot comments and their ratings reflected limitations of the Compu-Scene IVA image generator and the data base. At the time of the evaluation, Site 2 was performing an air-to-air evaluation and both the image generator and the data base had been optimized for air-to-air operations. The lack of detail in some of the ground targets may have been due to optimization of the data base for air-to-air operations. Comments concerning abrupt enhancement of object detail are a reflection of limitations in the image generator. During interviews conducted at the

conclusion of the evaluation, all of the pilot evaluators indicated that they would like to evaluate the DART with a higher capability image generator and an improved data base.

3.2.2.4 Head-tracking. The majority of evaluation pilots reported that the head-tracking for the DART and Mini-DART was adequate. However, several pilots commented the on/off switching of the display scene for the aft display panel was noticeable and distracting. The switching occurs to share a single channel of the image generator aft of the cockpit. The scene is switched to the left or right rear channel depending upon which direction the pilot is looking. When the pilot turned their heads quickly to the rear, they would see the switching occur. During the evaluation, pilots reported that sometimes the aft panel displayed an incorrect scene.

3.2.2.5 Availability. The issue of operational suitability was not an objective of the evaluation. However, during the evaluation, very few missions were lost due to hardware or software problems. These missions were quickly made up. As mentioned above under the issue of head-tracking, some of the pilots noted that infrequently an incorrect scene would be displayed on the wrong panel of the visual display. The site engineer noted the problem and made quick fixes to the display

3.2.2.6 Sound. This simulation had a sound system that provided the pilots with engine noise. Pilots commented that this was helpful in performing their mission tasks.

3.2.3 Additional Findings for Site 3 (FOHMD).

3.2.3.1 Resolution. Pilots and WSOs indicated that the resolution of the AOI was very good but that the resolution in the area outside the AOI needed improvement. Pilots indicated that they use their peripheral vision to detect targets and object movement. Pilots and WSOs also indicated that resolution was substantially degraded by the broken fiber optic bundles that occurred during the evaluation.

3.2.3.2 Brightness. Pilots commented very favorably upon the brightness of the display. However, display brightness was degraded as fiber optic bundles were broken during the evaluation.

3.2.3.3 Tornado Fighter Cockpit. (Transition to a wing-sweep aircraft) Pilots and WSOs did not have any problem transitioning to flying the Tornado fighter simulator. Although none of the pilots had flown an aircraft with adjustable wing sweep, the transition to the Tornado was accomplished with minimum difficulty. The site had several simulator instructors who had previous Tornado flight time and they provided excellent instruction on the flight characteristics and system operation. The majority of the Pilots and WSOs commented favorably on the FOHMD implementation of the masking for the cockpit sill, canopy bow, aircraft structures and HUD. Pilots and WSOs indicated a major difficulty with the FOHMD was obtaining cockpit information from the weapons radar display or other instruments. Most pilots and WSOs stated that due to difficulty of seeing through the display optics, they had to fixate (rather than quickly glance) on a cockpit display to

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get information. The majority stated that sometimes they resorted to looking under the FOHMD optics to obtain information from the weapons radar or other displays during their mission.

3.2.3.4 Image Generator and Data Base. The pilots and WSOs liked the Germany data base. The majority of the evaluation aircrews had flown over similar areas of Germany during deployments or while stationed in Europe. They commented that the data base had obviously been optimized for the low altitude regime because they noted that the data base was not as realistic at high altitudes as it was for low altitude. Pilots and WSOs commented that the data base gave an adequate portrayal of the forest canopy (tops of the trees) that permitted them to fly visually at low altitudes. They indicated that forest canopies for data bases intended for visual low altitude flight should show individual trees of different heights within the forest. Color texturing is an aid, but not the complete answer, to providing pilots information about altitude. Pilots and WSOs indicated that they would like to have multiple levels of texturing so that as they became closer to the texture it would become more distinct rather than staying fuzzy. All pilot and WSO evaluators stated that they would like to see the FOHMD evaluated with a higher capability image generator such as the ESIG-4000 or Compu-Scene VI.

3.2.3.5 Head Tracking and Eye Tracking. The majority of the evaluation missions were flown using eye-tracked AOI. Pilots liked this feature when it was used. They commented that the AOI needs to be made larger and there needs to be better resolution in the background channel of the visual display. Pilots who used the head tracked AOI indicated they had to change their visual scan pattern from their normal scan pattern. The majority of pilots reported eye-tracking is closer to normal since fighter pilots move their eyes rather than their head to look at an object. During the evaluation, several of the pilots noticed it was possible to exceed the limits for the pupil tracker. Several evaluation pilots reported jitter and bounce of the eye tracked AOI when rapid head movements were made. Pilots also reported noticing some lag in the tracking of the AOI.

3.2.3.6 Eye Tracking and Calibration Process. The procedures needed to provide eye tracking required that each pilot and WSO evaluator have a special custom fitted helmet liner. It also required a special eye tracking alignment process be conducted in the cockpit after the pilot or WSO had strapped in.

3.2.3.6.1 The helmet liner was made of a plastic-like foam and inserted inside the hard helmet that held the optical display components of the FOHMD. The liner required each evaluator to have the helmet poured into a mold worn by the evaluator. Once the foam had hardened, a specially trained technician at Site 3 conducted preliminary bore sighting and alignment of the helmet. This process required approximately one hour to accomplish and, with the exception of the bore sighting and alignment, was very similar to the process used by USAF to custom fit helmets for aircrews. The process used to accomplish the in-cockpit eye tracking alignment and calibration process was as follows: Prior to the mission, technicians would insert the evaluators custom helmet liner into the FOHMD helmet. The pilot or WSO would enter the cockpit and strap in. Technicians

would lower the helmet on to the evaluator and accomplish initial adjustments to insure that the FOHMD was snug and as comfortable as possible. During this initial adjustment, the technicians would insure that the exit pupil for the visual display was properly adjusted to view the display. Next, a technician outside the cockpit would have the evaluator perform several eye movement exercises to align the eye tracking system. The strap-in and FOHMD alignment process required approximately 15 minutes to accomplish and required a minimum of two technicians to properly accomplish.

3.2.3.6.2 During several of the missions, the alignment process was accomplished but the system could not maintain eye tracking. In these few instances, if the mission was in progress and eye tracking was not working, then the mission was continued. If the mission was not in progress, then realignment for the eye tracking was attempted. The alignment process required additional time. Pilot and WSO comments indicated that the helmet pouring process was not objectionable since it was a process they normally undergo for their own custom helmet liners. Of some concern to the evaluators was that the eye alignment procedures were time consuming, required additional specially trained technicians to accomplish, and did not always work. The majority of the evaluation team believed that when eye tracking was working the display was definitely better than without eye tracking. Pilots and WSOs commented that the delay in the eye tracker was noticeable but still better than without eye tracking. Several of the evaluators commented that they experienced noticeable jitter of the eye tracked area of interest.

3.2.3.7 Head Movement Limitations. A major negative criticism of the display concerned the restrictions to normal head movement with the FOHMD. The routing of the fiber optic bundles restricted head movement and required extra effort on the part of the user when looking aft of the three-nine line. Due to their size and location, pilots reported difficulty in checking 6 o'clock and at the high 12 o'clock position. This restriction was caused by the thickness and lack of flexibility of the fiber optic cables as they encountered the shoulder of the user. Pilots and WSOs both admitted that to look at a target aft of the 4 o'clock or 8 o'clock position or their deep 6 o'clock position, they would use their hands to push the helmet around; this would keep the display from moving and avoid visually losing the image display. As a result of the cumbersome cables, pilots often reported that they became less aggressive than normal in their head movements. Representatives at Site 3 indicated that at Neuberg AB GE the fiber optic cables had been routed to the rear of the helmet and given support to provide more flexibility of head movement. This installation had been made on a German F-4 flight simulator. The lead evaluation pilot and a WSO traveled to Neuberg AB GE. Results of their evaluation are presented in Paragraph 3.3.1.

3.2.3.8 Fiber Optic Bundle Wear. Over the period of the evaluation, movement of the fiber optic cables resulted in breakage of the individual fiber optic bundles. The result was a darkening of the displayed image. The darkening of the display was often referred to as the screen door effect because the appearance of the imagery looks as if one was viewing through a screen door. The dark spots caused by breakage of the fiber optic bundles was detrimental to tasks involving visual detection of friendly aircraft or threats

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and target identification because the pilot or WSO had to devote extra time to differentiate between a spot caused by a broken fiber optic bundle and an actual target. During the one week evaluation, the fiber optic cables for the pilot and WSO positions were not replaced and fiber optic bundle breakage became very noticeable.

3.2.3.9 Motion Simulation. The integrated motion systems at Site 3 were representative of the latest state of the art in motion systems. This was the only evaluation site where motion simulation was available. Pilots and WSOs commented that the combination of the 6-Degree of Freedom platform motion system, g-seat, and g-suit provided very realistic motion cueing. Comments ranged from evaluators not noticing that the motion system was on to pilots commenting that the motion was the most realistic they had ever experienced. The consensus was that the motion simulation was outstanding; however its impact to training is unknown.

3.2.3.10 Availability. The issue of operational suitability was not an objective of the evaluation. However, during the one week evaluation period, the Tornado simulation including the FOHMD and image generation system was very reliable and only a few missions had to be rescheduled. All missions were flown as planned.

3.2.3.11 Sound. The Tornado simulation included engine noise. Pilots commented that simulation of engine noise was useful and contributed positively to the overall aircraft simulation

3.3 OTHER SITES VISITED BUT NOT EVALUATED

3.3.1 Fiber Optic Helmet Mounted Display (FOHMD), Neuberg AB GE.

3.3.1.1 This site was visited by the lead evaluation pilot and a WSO who had participated at Site 3. Purpose of the visit was to fly the German F-4 flight simulator equipped with a FOHMD similar to the device at Site 3. The primary difference in the FOHMD devices was that the fiber optic bundles were routed out and to the rear of the helmet rather than out and down as had been the case at Site 3 (see Figure 3-22.). The major benefits of the different fiber optic bundle routing were decreased wear on the bundles and easier less restricted lateral and vertical head movement than the Site 3 system. The German F-4 weapon system has an air-to-air mission. Therefore, the data base and the image generator were optimized for the air-to-air mission. The system had a FOHMD for the pilot and a FOHMD for the WSO.

Figure 3-22.   German FOHMD in F-4 at Neuberg AB GE.

3.3.1.2 Several missions were flown in the system. It was the consensus of the lead evaluation pilot and the WSO that the change in cable routing does significantly improve the ease of moving the display and was less restrictive of head movements. It was also noted that looking inside the cockpit while using the FOHMD was slightly improved over Site 3.

3.3.2 ESPRIT Visual System, RAF Wittering UK.

3.3.2.1 The lead evaluation pilot visited the RAF Harrier simulator with ESPRIT visual system and flew several missions. Development of this visual system was initiated in the United States but was not placed on any Air Force trainers. The RAF acquired the system and uses it as their primary training device for the Harrier. The system has a motion system consisting of a platform motion base and g-suit. The visual system uses both head-tracking and eye-tracking to move a high resolution AOI where the pilot's eyes are looking. The eye tracking requires that the pilot wear a special adjustable helmet and that the system be calibrated to the pilot's eyes. In the event that eye tracking can not be used (due to time constraints or inability to calibrate the system to the pilot), then the high resolution AOI is slaved to the pilot's head. Since the Harrier's mission is primarily air-to-surface, the data base and the MOD DIG image generator were optimized for air-to-surface.

3.3.2.2 The lead evaluation pilot flew several missions in the system. The pilot reported that the system is very capable and appears to be much brighter than other domes he has experienced. Many of the problem areas identified at Site 1 (helmet tracked AOI, dome brightness, full aircraft cockpit fidelity, integrated weapons system, etc.) were corrected in the Harrier system. Additionally, the database in the ESPRIT is optimized for air-to-ground missions. The following are comments from the lead pilot, "Comments at Site 1 indicated that these improvements would significantly increase training capability and the

ESPRIT System gives us the ability to measure impact of these improvements on training capability. The improved dome technology, training system fidelity, optimized data base, and eye-tracked AOI make a study of this system critical to this evaluation."

3.3.3 Other Evaluation Team Findings and Discussion

3.3.3.1 During the evaluations, several manufacturers of display technology indicated interest in having the evaluation team perform similar evaluations on their display systems. The team believes that efforts of this type should continue to be conducted to ensure those display technologies that are acquired possess the capability to train the intended tasks. Several of the sites evaluated in the present effort indicated that they plan improvements to the display technologies that were evaluated. These improvements should be evaluated when feasible.

3.3.3.2 This series of evaluations used twenty-six tactical tasks for the pilot evaluation and twenty-two tactical tasks for the WSO evaluation. Use of these tasks in relation to the rating scale served as the common standard for the evaluation across all systems. Although the focus of this evaluation was visual display systems, few of the tasks were purely visual since most required a tactical cockpit capability to support the mission scenarios. The evaluation team believe that future evaluations of candidate tactical visual systems should use a command coordinated list of specific visual tasks as a standard for visual system evaluation.

3.3.3.3 During the evaluations of the different visual display technologies, the importance of the cockpit and the integration of the cockpit systems to the visual system was identified as a major factor in the evaluations. The fighter aircrew's world is viewed within and around their cockpit. As most of the evaluation pilots and WSOs indicated, there are very few purely visual tactical flying tasks in the real world. All of the evaluation tasks required the use of cockpit systems information in addition to the visual display information. In some instances such as the two-channel AOI dome, limitations of the cockpit limited the ability of the evaluators to perform several tasks. The team believes that future visual system evaluations must consider the impact of tactical cockpits in relation to the visual system capabilities.

3.3.3.4 The team believes that each visual display technology should be viewed in terms of the training capability to train a particular task and not just in terms of the number of evaluation tasks rated as trainable. In some instances such as the DART, the number of tasks that were rated as trainable was heavily influenced by the cockpit system; in others such as the two-channel AOI dome display ratings of the visual system were adversely impacted by cockpit limitations. The evaluation team recognizes that there will be a tendency on the part of many readers to try to use the numbers of tasks as a metric of the display technology. This is not appropriate. Comparisons between display technologies in this evaluation are not appropriate due to the many major differences between the systems., e.g., image generators, data bases, scene content, and cockpit systems.

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3.3.3.5 Throughout the visual evaluations, the importance of area of coverage, scene content, and scene detail of the visual presentations for operational training continued to surface. The evaluation team believes that realistic low altitude operational fighter training requires large visual data bases, with realistic threat modeling, high scene content, and high scene detail. Large data bases are required because tactical jet aircraft cover long distances in very short time spans. During the evaluations at all three sites, it was not uncommon to fly off the data base; this is disconcerting to the aircrew and destroys the situational realism. Threat models must be accurate so that the aircrew member trains as they would fight. Poor threat modeling destroys the situation realism if it is a type of threat previously experienced. Poor threat modeling can also result in teaching poor, potentially fatal, threat reaction if it is a threat not normally experienced except in combat. Scene content is important because it provides the aircrew member with additional visual information. Instead of representing a city with a single building, important landmark buildings can and should be presented. Forests can be populated with trees of different sizes and shapes to provide vital cues for flying low altitude. Scene detail is important to the pilot because it provides yet another vital visual cue to the pilot. Instead of soldiers appearing as "stick figures" soldiers on the ground can be shown operating weapons. Scene detail can enable aircrew members to distinguish between civilian and military dress or threats and non-threats.

3.3.3.5.1 To accommodate realistic threat modeling, scene content, and accurate data bases requires a high end image generator. Image generators presenting data bases for tactical training must be able to rapidly process large quantities of data in a timely manner so that the aircrew member can realistically see it. When the image generator becomes overloaded, visual data appears to pop in to the scene, distortions can occur, the picture can flicker, etc.

3.3.3.5.2 The data base for the FOHMD (Site 3) was representative of the minimum acceptable for operational training tasks but requires enhancement of the scene detail for low altitude training. Future training systems should include data bases and image generators that meet the above requirements.

3.3.3.6 The team believes that evaluations of this type should be accomplished using senior instructor pilots or WSOs. Highly experienced instructor pilots and instructor WSOs are experienced in teaching flying principles to new students as well as experienced aircrew members returning to flying. They know what it takes to train the full range of students and can comprehensively express training issues to other disciplines so that they are understood.

3.3.3.7 Overall, the evaluation team believed that texturing in the displayed image can provide helpful cues for low altitude flight. However, a single level of texturing does not provide adequate cues required by pilots for low altitude flight using visual information. Texturing should become sharper in focus as the range from the textured object decreases. Multiple levels of texturing are a possible solution and should be evaluated.

3.3.3.8 Simulator sickness was not the focus of this evaluation. There were no major instances of simulator sickness reported in any of the three evaluations. The evaluation team does not believe simulator sickness to be a problem with any of the technologies evaluated. However, the questionnaire given to each evaluation pilot or WSO at the completion of each mission did ask information about simulator sickness. If the evaluators indicated experiencing any physiological effects (headaches, nausea, or eye strain) then they were asked to expand on the problem during the debrief at the conclusion of completing the questionnaire. A total of 99 missions were flown during the evaluation of the three display technologies (Two-Channel AOI Dome, DART and Mini-DART, and FOHMD).

3.3.3.8.1 There were no substantive responses to simulator sickness on the Two-Channel AOI Dome. Three responses expressed eye strain; this was determined to be due to pilots squinting trying to see objects. Thus, lack of adequate resolution may have caused these pilots to have eye strain. The effects had disappeared by the time of the debrief. A single pilot reported having a headache. Further interviews indicated that the problem was gone by the time of the interview. A single response indicated disorientation that was found not to be due to the simulation. The remaining responses were from one pilot who flew two missions during the day and reported nausea during the missions; during the debrief, he indicated that he had nausea prior to the simulator.

3.3.3.8.2 There were no substantive responses to simulator sickness on the DART or Mini-DART. Comments were related to temperature inside the DART.

3.3.3.8.3 There were no substantive responses to simulator sickness on the FOHMD. Comments were related to fit of the helmets, three reports of eye strain due to trying to use the eye-tracked AOI, and cockpit temperature. There were no after effects reported during the debriefs.

3.3.3.9 Based upon the three evaluations, the evaluation team believes that single ship air-to-ground tasks are trainable now with the right combination of database, image generator, and matched visual display system. Review of the data indicates that many of the critical air to ground tasks such as combat descent, single ship low level, visual navigation to an Initial Point, low altitude weapons delivery, high altitude weapons delivery and air to ground reattack, were rated trainable on at least two or more systems. AIM-9 and air-to-air gun employment also were rated trainable on at least two or more systems but these tasks were considered after the aircraft was in firing position. If improvements were made to the Two-Channel AOI Dome such as inclusion of a realistic fighter cockpit, many of these air to surface tasks might become trainable.

3.3.3.10 The evaluation team does not believe that current systems provide adequate resolution, contrast, and brightness to allow for dynamic air model discrimination. Dynamic air models refer to anything (another aircraft, SAM, air-to-air missile, flack, bullets, etc.) in the airspace that the pilot or WSO must assess it's attitude, range, etc. In reviewing the data, tasks such as move to tactical formation, tactical formation above and

below 500 feet, visual lookout/mutual support, detect visual threats, single ship threat reactions, coordinated air to ground attack, reform after air to ground attack low altitude intercept, flight lead responsibilities, and wingman responsibilities, were never graded fully trainable on the systems evaluated.

3.3.3.11 This evaluation considered only operational training capability for each visual display capability. If a visual system acquisition was planned, then other factors such as life cycle costs, logistics support, ease of use, etc., must be considered in relation to training capability.

SECTION 4 CONCLUSIONS AND RECOMMENDATIONS

4.1 CONCLUSIONS.

Page and paragraph references shown below contain supporting data relating to each conclusion.

4.1.1 The Two-Channel AOI Dome was evaluated as being capable of supporting operational pilot training, mission qualification training, and continuation training for a limited number of tasks (page 15, para. 3.1.1.2.1.3; page 36, para. 3.1.2.1.2.1.1 and para. 3.1.2.1.2.1.2; page 43, para. 3.1.2.2.2.1.1; and page 44, para. 3.1.2.2.2.1.2).

4.1.2 The DART visual system was evaluated as being capable of supporting operational pilot training, mission qualification training, and continuation training for a limited number of tasks (Page 20, para. 3.1.1.2.2.3; page 37, para. 3.1.2.1.2.2.1: page 38, para. 3.1.2.1.2.2.2; page 45, para. 3.1.2.2.2.2.1; page 46, para. 3.1.2.2.2.2.2).

4.1.3 The mini-DART was evaluated as being capable of supporting operational pilot training for a limited number of tasks (page 25, para. 3.1.1.2.2.15).

4.1.4 The FOHMD visual system was evaluated as being capable of supporting operational pilot training, mission qualification training, and continuation training for a limited number of tasks (page 27, para. 3.1.1.2.3.3; page 39, para. 3.1.2.1.2.3.1; page 40, para. 3.1.2.1.2.3.2; page 47, para. 3.1.2.2.2.3.1; page 48, para. 3.1.2.2.2.3.2).

4.1.5 The FOHMD was evaluated as being capable of supporting operational WSO training, mission qualification training, and continuation training for a limited number of tasks (page 32, para. 3.1.1.2.4.3; page 41, para. 3.1.2.1.2.3.3; page 42, para. 3.1.2.1.2.3.4; page 49, para. 3.1.2.2.2.3.3; and page 50, para. 3.1.2.2.2.3.4).

4.1.6 For the Two-Channel AOI Dome visual system, lack of normal fighter cockpit avionics precluded accomplishment of several of the evaluation tasks (page 14, para. 3.1.1.2.1.2) and adversely affected some training capability ratings (page 19, para. 3.1.1.2.1.17).

4.1.7 No performance testing of any visual system configuration was required. All performance data was available in current visual system documentation, and was verified with the visual system development engineers. The Two-Channel AOI Dome (page 51, para. 3.1.3.2.1), DART and mini-DART (page 53, para. 3.1.3.2.2), and FOHMD (page 54, para. 3.1.3.2.3) were similarly baselined and the engineering attributes documented in accordance with the objectives.

4.1.8 A wider field of view is required for both the inset AOI and the background scene for the Two-Channel AOI Dome (page 54, para. 3.2.1.1).

4.1.9 The target projector for the Two-Channel AOI Dome produced a target image that was too bright (page 54, para. 3.2.1.2).

4.1.10 Lack of a fighter cockpit and HUD adversely impacted the results for the Two-Channel AOI Dome (page 54, para. 3.2.1.3).

4.1.11 The data base use for the Two-Channel AOI Dome evaluation needed more cultural and geographic detail (page 54, para. 3.2.1.4).

4.1.12 Head-tracking with the Two-Channel AOI Dome forced the pilots to use exaggerated head movements to acquire a visual target (page 55, para. 3.2.1.5)

4.1.13 Availability for the Two-Channel AOI Dome, DART, and FOHMD was excellent (page 55, para. 3.2.1.6; page 56, para. 3.2.2.5; page 59, para. 3.2.3.10).

4.1.14 Resolution of the DART and Mini-DART was not adequate at ranges outside 3000 to 5000 feet.

4.1.15 Brightness of the DART, Mini-DART and FOHMD was very good (page 55, para. 3.2.2.2; page 56, para. 3.2.3.2).

4.1.16 Limitations of the Site 2 image generator and the data base adversely impacted pilot ratings (page 55, 3.2.2.3)

4.1.17 Head-tracking for the DART and Mini-DART was adequate (page 56, para. 3.2.2.4)

4.1.18 Sound simulation used on the DART, Mini-DART, and FOHMD was helpful to perform mission tasks (page 56, para. 3.2.2.5; page 59, 3.2.3.11).

4.1.19 Resolution of the AOI for the FOHMD was very good but resolution in the area outside the AOI needs improvement (page 56, para. 3.2.3.1)

4.1.20 Resolution of the FOHMD was substantially degraded by broken fiber optic bundles that occurred during the evaluation (page 56, para. 3.2.3.1).

4.1.21 A major difficulty with the FOHMD was to obtain cockpit information from the weapons radar display or other instruments (page 56, para. 3.2.3.3)

4.1.22 The Site 3 data base used on the FOHMD was liked by both pilots and WSOs and permitted visual flight at low altitudes (page 57, para. 3.2.3.4).

4.1.23 The eye tracking feature of the FOHMD was liked by pilots and WSOs (page 57, para. 3.2.3.5).

4.1.24 The FOHMD required a special helmet liner and calibration procedure for use (page 57, para. 3.2.3.6).

4.1.25 The FOHMD fiber optic cable routing at Site 3 restricted head movement and required extra effort on the part of the user when looking aft of the three-nine line (page 58, para. 3.2.3.7).

4.1.26 Fiber optic cable routing for a FOHMD at Neuberg AB GE significantly improved ease of using the FOHMD (page 59, para. 3.3.1).

4.1.27 Movement of the fiber optic cables during normal flying use produced breakage of individual fiber optic bundles and darkened the displayed image (page 58, para. 3.2.3.8).

4.1.28 The integrated motion systems of 6 degree of freedom platform motion, g-seat, and g-suit used with the FOHMD, provided realistic motion cueing (page 59, para. 3.2.3.9).

4.1.29 The ESPRIT visual system installed on the Harrier weapon system trainer was judged to be a very capable system and should be evaluated by the USAF (page 60, para. 3.3.2).

4.1.30 Single levels of texturing do not provide adequate information about distance and range. Texturing should become sharper in focus as the range from the textured object decreases (page 63, para. 3.3.3.7).

4.1.31 There were no major instances of simulator sickness reported in any of the three evaluations (page 63, para. 3.3.3.8)

4.1.32 Based upon the technologies evaluated, single ship air-to-ground tasks are trainable now with the right combination of database, image generator, and matched visual display system (page 64, para. 3.3.3.9).

4.1.33 Current systems do not provide adequate resolution, contrast, and brightness to allow for dynamic air model assessment (page 64, para. 3.3.3.10).

4.2 RECOMMENDATIONS.

4.2.1 The evaluation process should be continued to test Combat Air Forces (CAF) training tasks against visual system capabilities. This process will enable the user and acquisition community to develop more realistic expectations of training systems capability. The process will provide the acquisition community with increased confidence levels and a reduction of risk.

4.2.2 Manufacturers of visual systems that use area of interest (AOI) need to make these systems less awkward and more acceptable to pilots.

4.2.3 Users should establish simulator training expectations that are consistent with visual systems capability. Image generators, databases, and visual display systems must be matched in design and capability to realistic training requirements. Any weak link will be the limiting factor.

4.2.4 A future required capabilities list for CAF training is needed to steer research and development.

4.2.5 MAJCOMs should work closely with the acquisition community to determine training tasks relying on visual simulation to support the following; Formal Training Unit (FTU) training to near Mission Ready (MR) capability flight simulator requirements; Continuation Training (CT) requirements for future flight simulators; Specific training requirements and mission objectives of Unit Training Devices (UTDs) and Weapon System Trainers (WSTs); and Local Area Networks (LAN) and Distributed Interactive Simulation (DIS) training requirements for the CAF.

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ANNEX A BACKGROUND OF EVALUATORS

Background of Evaluation Pilots.

Eight pilots were randomly selected for this evaluation. All pilots had fighter experience and instructor pilot experience, with two of the pilots having combat experience. One of the pilots had also had helicopter flying and instructor experience. The average flying time for the pilots was 1989 hours. The average instructor time for the pilots was 1039 hours.

Background of Evaluation Weapon System Operators.

Three weapon system operators (WSO) were randomly selected for this evaluation. The two WSOs went to the third site only (Stolberg, Germany) to evaluate various training task capabilities of the visual display used on the Tornado simulator. All WSOs had WSO instructor experience. One WSO had combat experience. The average flying time for the WSOs is 2213 hours. The average instructor time for the WSOs was 983 hours.

ANNEX B LIST OF PILOT AND WSO TASKS AND EVALUATION MISSIONS

Number	Pilot Tasks
1	Tanker rendezvous
2	Tactical formation from fingertip
3	Tactical formation above 500 feet
4	Combat descent
5	Tactical formation below 500 feet
6	Single ship low level
7	Visual low level navigate to initial point
8	Mutual support/lookout in various tactical formations
9	Detect visual threats
10	Detect electronic threats
11	Terrain Masking (direct/indirect)
12	Individual/formation threat reactions
13	Tactical instruments cross check
14	Visual target acquisition/identification
15	Coordinated tactical attack
16	Low altitude weapon delivery (LAS, LALD, LAB, VLD)
17	High altitude weapon delivery (HAS, HD, DB, DTOS)
18	Reform after tactical attack
19	Target reattack
20	Aircraft battle damage check
21	Low altitude intercept
22	AIM-9 employment
23	Low altitude air-to-air gun employment
24	Flight lead responsibilities
25	Wingman responsibilities
26	Situational awareness of tactical situations

Table B-1   List of Evaluation Tasks for Pilots

Number	WSO Tasks (Site #3A Only)
1	Single ship low level
2	Visual low level navigate to initial point
3	Mutual support/lookout in various tactical formations
4	Intraflight coordination/communication
5	Intercockpit coordination/communication
6	Detect visual threats
7	Detect electronic threats
8	Tactical instruments cross check
9	Visual target acquisition/identification
10	Coordinated tactical attack
11	Low altitude weapon delivery (Radar/EO)
12	High altitude weapon delivery (Radar/EO)
13	Reform after tactical attack
14	Target reattack
15	Aircraft battle damage check
16	Low altitude intercept
17	Situational awareness of tactical situations
18	Direct tactical formation
19	Direct individual/formation threat reactions
20	Direct target attack/reattack
21	Direct reform
22	Direct egress

Table B-2   List of Evaluation Tasks for WSOs at Site 3.

Number	Mission
0	Familiarization
1	Single Ship Low Level
2	Single Ship Low Level with Threat Reactions
3	Formation Low Level with Threat Reactions

Table B-3   Missions Flown at Each Evaluation Site.

Profile Development

Training profiles for each simulator were developed prior to the arrival of the full team. The lead instructor pilot and WSO arrived early to determine the capabilities of the database and hardware to support Vis-Eval team objectives. Mission objectives and profiles were kept the same where possible for all devices and visual systems. However, mission specifics were quite different based on hardware capability and available data bases. For example, Site #1 did not have an actual training cockpit and HUD to allow use of actual weapons delivery techniques. A small light marker on the dome was used as a "pipper" to simulate a gunsight. Although not ideal, this was an acceptable solution for the evaluation of the visual system.

The structure of the missions supported a rapid learning curve based on the high level of experience of the evaluators. A familiarization ride was flown that included all tasks to

be flown throughout the profiles to allow pilots to get a feel for the flight characteristics of the simulator and basic proficiency on systems employment. Mission #1 was a single ship low level mission with three ground target attacks to train the basics of visual low altitude flying and target acquisition. This mission was always flown at 500 feet above ground level (AGL), an artificially high altitude, to determine if visual references could be used to maintain an altitude above the natural comfort level of the pilots while accomplishing mission tasks. Mission #2 was always a repeat of profile #1 flown at 200 feet AGL or 300 feet AGL (pilot choice based on comfort level) with air and ground threats and threat reactions added to test for visual detection, defensive maneuvering, and general situational awareness in the visual environment. Mission #3 added formation tasks (mutual support, threat reactions, tactical formation, etc.) to the high threat low altitude profiles flown on mission #2. At Site #1 and Site #3, all missions were flown over the same database with similar threats, however, Site #2 could not support threats for the formation in the "air to ground" database, and mission #3 was flown in a database designed for air-to-air training. This did not impact the evaluation or mission objectives.

Site 1: Evans and Sutherland

Familiarization

Mission objective: Familiarize crew members with cockpit functions and capabilities. Develop basic skills for employment of the system within the visual environment, practice basic skills to be employed in the mission scenarios.

Mission profile: Visual trail departure, rejoin, close formation, straight and level tactical formation, single ship low level, visual lookout (airborne threats), terrain masking, 20 degree pop-up delivery, 30 high altitude delivery, 10 degree low altitude reattack, target egress, visual airborne target attack.

Mission 1: Single ship low level

Mission objective: Single ship low level skills application. Maintain 500 feet AGL and accomplish all single ship low level tasks.

Mission profile: Single ship departure, low level, visual lookout (airborne threats), terrain masking, 20 degree pop-up delivery, 30 high altitude delivery, 10 degree low altitude reattack, target egress, visual target attack.

Mission 2: Single ship low level with threat reactions

Mission objective: Use single ship low level skills to fly at 300 feet AGL or 200 feet AGL but no lower than pilot comfort level with increased mission tasks such as threat reactions and unexpected reattack requirements.

Mission profile: Combat descent, low level, visual lookout (airborne threat and ground threats), threat reactions terrain masking, 20 degree pop-up delivery, 30 high altitude delivery, 10 degree low altitude reattack, target egress, visual target attack.

Mission 3: Formation low level with threat reactions

NOTE: The second aircraft in this profile flew a preprogrammed route. Coordinated target attacks and formation threat reactions were not accomplished, however, rejoining with the wingman was accomplished after attacks were accomplished.

Mission objective: Fly tactical formation at 300 feet AGL or 200 feet AGL but no lower than pilot comfort level with increased mission tasks such as threat reactions and unexpected reattack requirements. Evaluate low visibility presentations and visual intercept capability.

Mission profile: Combat descent, tactical formation (flown as wingman), visual lookout (airborne and ground threats), threat reactions, terrain masking, 20 degree pop-up delivery, 30 high altitude delivery, 10 degree low altitude reattack, target egress, low altitude intercept, high to low intercept.

Site 2: Armstrong Laboratories

Familiarization

Mission objective: Familiarize crew members with cockpit functions and capabilities. Develop basic skills for employment of the system within the visual environment, practice basic skills to be employed in the mission scenarios.

Mission profile: Single ship low level flying , 20 degree pop-up delivery, 10 degree low altitude reattack, target egress, visual airborne target attack.

Mission 1: Single ship low level

Mission objective: Single ship low level skills application. Maintain 500 feet AGL and perform all single ship low level tasks.

Mission profile: Combat descent, low level, visual lookout (airborne threats), terrain masking, 20 degree pop-up delivery, 30 high altitude delivery, 10 degree low altitude reattack, target egress, visual target attack.

Mission 2: Single ship low level with threat reactions

Mission objective: Use single ship low level skills to fly at 300 feet AGL or 200 feet AGL but no lower than pilot comfort level with increased mission tasks such as threat reactions and unexpected reattack requirements.

<u>Mission Profile</u>: Combat descent, low level, visual lookout (airborne and ground threats), threat reactions, terrain masking, 20 degree pop-up delivery, 30 high altitude delivery, 10 degree low altitude reattack, target egress, visual target attack.

Mission 3: Formation low level with threat reactions

<u>Mission objective</u>: Fly tactical formation at 300 feet AGL or 200 feet AGL but no lower than pilot comfort level with increased mission tasks such as threat reactions and unexpected reattack requirements. Evaluate low visibility presentations and visual intercept capability.

<u>Mission Profile</u>: Combat descent, join-up, tactical formation (flown as wingman), visual lookout (airborne and ground threats), threat reactions, terrain masking, 20 degree pop-up delivery, 30 high altitude delivery, 10 degree low altitude reattack, target egress, low altitude intercept, high to low intercept.

Site 3: CAE Stolberg, Germany (Tornado)

Familiarization

<u>Mission objective</u>: Familiarize crew members with cockpit functions and capabilities. Develop basic skills for employment of the system within the visual environment, practice basic skills to be employed in the mission scenarios.

<u>Mission profile</u>: Single ship takeoff, visual trail departure, rejoin, close formation, straight and level tactical formation, single ship low level, visual lookout (airborne threats), terrain masking, 20 degree pop-up delivery, 30 high altitude delivery, 10 degree low altitude reattack, target egress, visual airborne target attack.

Mission 1: Single ship low level

<u>Mission objective</u>: Single ship low level skills application. Maintain 500 feet AGL and perform all single ship low level tasks.

<u>Mission profile</u>: Single ship takeoff, departure, combat descent, low level, visual lookout (airborne threats), terrain masking, 20 degree pop-up delivery, 30 high altitude delivery, 10 degree low altitude reattack, target egress, visual target attack.

Mission 2: Single ship low level with threat reactions

<u>Mission objective</u>: Use single ship low level skills to fly at 300 feet AGL or 200 feet AGL but no lower than pilot comfort level with increased mission tasks such as threat reactions and unexpected reattack requirements.

Mission profile: Single ship takeoff, departure, low level, visual lookout (airborne and ground threats), threat reactions, terrain masking, 20 degree pop-up delivery, 30 high altitude delivery, 10 degree low altitude reattack, target egress, visual target attack.

Mission 3: Formation low level with threat reactions

Mission objective: Fly tactical formation at 300 feet AGL or 200 feet AGL but no lower than pilot comfort level with increased mission tasks such as threat reactions and unexpected reattack requirements. Evaluate low visibility presentations and visual intercept capability.

Mission profile: Single ship takeoff, visual trail departure, rejoin, close formation, tactical formation (flown as wingman), visual lookout (airborne and ground threats), threat reactions, terrain masking, 20 degree pop-up delivery, 30 high altitude delivery, 10 degree low altitude reattack, target egress, low altitude intercept, high to low intercept.

ANNEX C SAMPLE DATA COLLECTION FORMS

PILOT BACKGROUND QUESTIONNAIRE

NAME AND GRADE_____DATE_____

ORGANIZATION_____LOCATION_____

PILOT NUMBER_____TELEPHONE: COMMERCIAL_____
                                                     DSN_____
                                                     FAX_____

TYPE OF AIRCRAFT PRESENTLY FLYING: (Check one and indicate hours flown)
F-15C_____   F-15E_____   F-16C_____ Block #____
Hours flown_____   Hours flown_____   Hours flown_____
IP hours_____   IP hours_____   IP hours_____
Combat experience:

Aircraft Type:_____Combat Hours_____ Combat Missions_____

CURRENT AF DUTY: (e.g., instructor pilot, staff officer, etc)

_____

Other instructor and fighter aircraft flying experience: (list aircraft
and approximate hours).
_____

_____

_____

_____

List Total Flying Time_____   List Total IP Time_____

FORM 1

DATE:_____   TIME:_____

PILOT NAME/NUMBER:

LOCATION:

VISUAL SYSTEM CONFIGURATION:

VISUAL DISPLAY ADEQUACY QUESTIONNAIRE

This questionnaire is designed for you to rate the adequacy of the
visual display to permit you to train each individual task attempted
during each mission. One form should be completed by each evaluation
pilot after each mission. The simulator rating scale is provided as a
separate handout for reference along with the visual tutorial. After
each rating, please provide comments describing the reason for the
rating. Please contact the evaluation monitor if there are any
questions.

SECTION A

TASK:

1. Rate the training capability of the visual display for the above
task._____

NOTE: If you rated the training capability <u>less than 3</u> on this task,
please answer the following questions:

2. To accomplish the task, were you required to deviate from the normal procedure?   YES_____
                                                                        NO _____

    If yes, describe the deviations taken.
Comment:_____
_____
_____
_____

3. Did the visual resolution (object detail) affect the performance of the task?
Comment:_____
_____
_____

4. Did the visual field-of-view (viewable area) affect your rating of the task?   YES_____
                                                                        NO_____

Comment:_____
_____
_____

5. Did the visual brightness (object detail) affect your rating of the task?   Yes_____
                                                                        NO_____

Comment:_____
_____
_____

6. Did the visual contrast (object detail) affect your rating of the task?   Yes_____
                                                                        No_____

Comment:_____
_____
_____

7. Did the visual collimation (range of image) affect your rating of the task?   Yes_____
                                                                        No_____

Comment:_____
_____
_____

8. Was the appearance of displayed objects distorted?   Yes_____
                                                            No_____

Comment:_____
_____
_____

9. In the accomplishment of this task, did lights or small objects appear blurry?   Yes_____
                                                                        No_____
Comment:_____
_____
_____

10. In accomplishment of this task, did the visual scene appear grainy?

Yes_____

No_____

Comment:_____

_____

_____

11. In accomplishment of this task, did the visual scene appear cartoonish?

Yes_____

No_____

If yes, did this impact your rating of the training value of the task?

Yes_____

No_____

Comment:_____

_____

_____

12. In accomplishing this task, did the visual scene display any blemishes?

Yes_____

No_____

Did these blemishes affect your rating of the training capability of the visual system for this task?

Yes_____

No_____

Comment:_____

_____

_____

13. In accomplishment of this task, did any spurious images affect your task performance?

Yes_____

No_____

If yes, please comment:_____

_____

_____

14. Did image continuity (image shifted up or down across display boundaries) across displays affect your rating of the task?   Yes_____

No_____

If yes, please comment:_____

_____

_____

15. In accomplishment of this task, did the area-of-interest insert affect your rating of the visual system?

Yes_____

No_____

If yes, please comment_____

_____

_____

16. In accomplishment of this task, did the visual image displayed appear to flicker, waver or any other anomalies appear when you moved your head from side-to-side?

Yes_____

No_____

If yes, did it affect your rating of the training capability for the task?

Yes_____

No_____

If yes, please comment:_____

_____

_____

17. Did the HUD/visual correlation affect your rating of the visual
system for this task?   Yes_____
                                                                No_____

If Yes, please comment:_____
_____
_____

18. In accomplishment of this task, did the visual scene appear to
flicker or vary in brightness?   Yes_____
                                                                No_____

Did it affect your rating of the task?   Yes_____
                                                                No_____

If so, please comment:_____
_____
_____

19. Did the eye and/or head tracked display affect your rating of the
training capability of the visual system (i.e., scene detail
consistency, AOI insert motion noticeable or AOI insert jitter or jump
when not moving)?   Yes_____
                                                                No_____

If yes, please comment:_____
_____
_____

20. Did displacement of your head from the eye point (viewing volume)
affect your rating of the visual system?   Yes_____
                                                                No_____

If yes, please comment:_____
_____
_____

ANNEX D TRAINING CAPABILITY RATING SCALE

Rating Scale

NR....Not Rated. Use NR to identify items or questions that do not apply to you or were not evaluated by you.

1.....No similarity between visual simulation and aircraft training. Cannot train requirement with visual system. Provides negative training and has major deficiencies.

2.....Little similarity between visual simulator and aircraft training. Only minimal training can be accomplished using visual system. Major modifications would be required to provide adequate training capability.

3.....Training capability is acceptable. Essential parts of the task can be taught with this visual system.

4.....Visual training capability is nearly equal to that experienced in the aircraft. Negligible, if any, modifications required to train tasks. Most of the task can be trained with this visual system.

5.....Training capability is equal to that experienced in the aircraft. Task can be fully trained with visual system.

ANNEX E DETAILED HARDWARE DESCRIPTION

SITE 1: EVANS AND SUTHERLAND

GENERAL	
Display Name	Head Tracked Area-of-Interest Dome
Display type	Head tracked area-of-interest insert into a head tracked background scene displayed on a 24 foot dome by light valve projectors
Location	Salt Lake City, Utah
Agency	Evans and Sutherland Corporation
Image generator	ESIG-3000 two channel system
Manufacturer	Evans and Sutherland Corporation
DISPLAY ATTRIBUTES	**P.O.C. Mark Larsen**
Resolution	Inset better than 6.9 arcmin per line pair Background is 20.6 arcmin per line pair
Field of view	Instantaneous FOV: Inset - 40 X 30, Background - 120 X 90 Total FOV: Inset - 42 X 32, Background 123 X 99 Optical FOV: Inset 38 X 28, Background - 110 X 88
Brightness	Specified at 2 foot-Lamberts Currently in dome 5 foot-Lamberts
Contrast ratio	15 : 1
Collimation	11 feet in forward field of view
Geometric distortion	Optimized with NLIM in forward field of view Not fully characterized elsewhere
Color Convergence	N/A for light valves
Video signal-to-noise	40 - 50 db nominal
Sweep signal-to-noise	N/A
Grey scale	7.8 at 15 : 1 contrast ratio and 50% duty cycle 12 bit video output
Colors	Full color
Blemishes	A few dust spots on NW edge of optical combiner Holes in dome for fiber-optic alignment point (Mistakes that have yet to be corrected)
Swimming	None
Spurious images	None
Image continuity	Better than 10 arcmin across the boundary from the inset to the background
Area-of-interest blending	Optical blending with 1 to 1.5 degree circular blend ring
HUD/Display focus	N/A
HUD/Display correlation	N/A (Specified at 6 arcmin with the inset centered in the HUD)
Refresh rate	60 hertz
Projector slew rate	Velocity - 20 radians per second Acceleration 40 radians per second per second
Tracking ability	Accuracy 0.1 degrees for the full field of view
Viewing volume	Better than a 30 cm diameter sphere
IMAGE GENERATOR ATTRIBUTES	**P.O.C. Allen Snow or Milt Sanders**
Translucency	24 levels

Texture	Advance texture capability. 4M texels, mix & match 1024 - 64 X 64, 256 - 128 X 128, 16 - 512 X 512, 64 - 256 X 256. 4 maps per polygon, bi-linear blending, moving, continuous (co-planar), projected. Photo, intensity, color, transparency, & contour.
Polygons	Inset - 2000 Background - 4000
Raster lights	Lights trade-off with polygons at 2.5 to 1. Can be modeled as small as 1 X 1 pixel. Range attenuation implemented. (Flashing, rotating, curved, strobed, moving, traffic, directional, etc.)
Calligraphic lights	None
Moving models	24 active models with 6 degrees of motion each capable of 2 articulated parts
Ambient light	Day, dusk, night, and continuous time of day (1024 steps)
Haze/Visibility	Yes. RVR ground and patchy ground fog included. Adjustable from 0 to 500 miles
Clouds	Two independent decks with and without scud on top and bottom. Adjust top and bottom of deck in increments of 1 foot from 25 miles MSL down to 1 foot MSL.
Horizon	Directional east/west horizon with glow for dusk. Movable for sun rise, sun set, and city glow.
Thunderstorm/Lightning	High, medium, and low storm with random lightning based on storm intensity. Visibility adjusts with range to storm. Only calligraphic lights blur. Visible lightning bolt with modeled storm otherwise flash only.
Special effects	Landing light lobes, wingtip and anti-collision light glare
Sun angle shading	Azimuth and elevation of sun position relative to the data base. Polygons shaded appropriately. Sun position moved for continuous time of day.
Surface shading	Smooth shading - Effected by sun angle but not uniform (Garaud) Fixed shading - Not effected by sun Flat shading- Effected by sun angle and uniform across polygon
Anti-aliasing	Proprietary algorithm. Greater than 16 X 16 subpixels. Screen door effect.
Visual range	0 to 500 miles
Level-of-detail ranges	User specified as to number and ranges. (Call Allen Snow)
Occultation levels	Range buffered system so it is limited by the number of pixels writes (E&S assumes a nominal 2.5 pixels writes)
Distracting effects	None. Frame rate changes first during overload. Maximum of 3 frames.
Update rate	60 hertz. Drops to 30 hertz during overload.
Transport delay	3.5 fields or approximately 58.3 milliseconds
Postional range & accuracy	For a 600 square nautical mile data base : +/- 0.006 degrees angular accuracy, 0.1 inch displayed position, and 0.05 inch modeled position.
Crash detection	Collision detection for features and moving models. Uses a collision volume about a point. Uses HAT for ground collisions. (Not enabled for Vis-Eval)
On-line data base	Approximately 600 miles. Environment memory is 32 Mbytes or approximately 140,000 polygons.
DATA BASE ATTRIBUTES	**P.O.C. Scott Campbell**

Geographic location	Hunter-Liggett (Not correlated to real world) Data base origin at 35.7 degrees north latitude and 121.5 degrees west longitude
Scene density	High detailed area - 2500 to 3000 polygons Transition area - 1250 to 1500 polygons
Model level-of -detail	Simple models - 3 levels of detail Complex models - 5 levels of detail Terrain- 5 levels of detail
Moving models	Tanks, SAM Site, F-18, F-14, MiG-29, F-16, SAM missile, Humvee, A-10, Apache, Hind, Phoenix missile, Sidewinder missile, AGM-65, Missile flash, Ground explosion. (Includes animation. Others can be built)
Model library	Basic model library.
Airfield library	No additional airfield models. Hunter-Liggett built for this data base.
Light models	No special light models, only those in basic model library.
Data base size	120 nautical miles by 90 nautical miles
Airfield area size	10 kilometers by 30 kilometers
Low altitude area size	60 nautical miles by 60 nautical miles
Air to ground area size	None
Texture maps	266 maps (4M texels)
Accuracy	0.05 inch
Polygon allocation	High detailed area - 1200 terrain polygons (Minimum size 1600 ft), 1500 feature polygons, and 300 model polygons. Transition area - 500 terrain polygons (Minimum size 11,482 ft), no features.
Source data	BBN Corp. for SIF data on Hunter-Liggett, JOG charts NI10-3 and NJ10-12, and DTED for transition area.

Note #1   Because the sensor was not level the displayed image tended to drift down or up, dependent on which way the level was off, as the pilot checked six. This was corrected so it did not impact the evaluation.

Note #2   Head tracker monitor was specified in the software to be within three feet of the sensor, so noise can be filtered but still get good response times. Further apart means you must reduce filtering to get good response, but you get more noise.
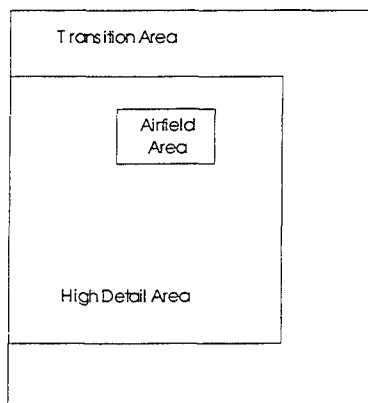
Data Base Layout

Table E-1   Site 1 Detailed Hardware Description. (AOI Dome)

SITE 2: ARMSTRONG LABORATORIES

GENERAL	
Display Name	Display for Advanced Research and Development (DART)
Display type	Real image CRT projection (Barco 600 projectors). Total of 9 projectors used in rear screen projection for wrap around viewing.
Location	Armstrong Laboratory, Williams AFB AZ
Agency	Armstrong Laboratory, Williams AFB AZ
Image generator	Advanced Visual Technology System (AVTS) - Compu-Scene IV prototype.
Manufacturer	General Electric Company
DISPLAY ATTRIBUTES	**P.O.C. Mel Thomas**
Resolution	4.48 arcminutes per pixel 9.5 arcminutes per line pair (Video of 985 lines horizontal by 1000 lines vertical)
Field of view	Azimuth : +/- 180 degrees Elevation : +90 degrees, -20 degrees
Brightness	15 foot-Lamberts average 25 foot-Lamberts center 10 foot-Lamberts edge
Contrast ratio	Greater than 100 : 1 50 : 1 with all screens illuminated
Collimation	Real image, flat screen viewing, 3.1 feet distance.
Geometric distortion	Less than 3%. No distortion correction algorithm.
Color Convergence	Adjusted for 0 error. Adjustable for proper registration.
Video signal-to-noise	
Sweep signal-to-noise	
Grey scale	
Colors	Full
Blemishes	Some - Did not affect viewing, they faded from perception.
Swimming	None
Spurious images	None
Image continuity	Edge matched across window boundaries (0 arcminutes).
Area-of-interest blending	None
HUD/Display focus	Separate projector displays HUD information in the front channel
HUD/Display correlation	Unknown
Refresh rate	60 hertz interlaced
Projector slew rate	N/A
Tracking ability	N/A
Viewing volume	N/A
IMAGE GENERATOR ATTRIBUTES	**P.O.C. Jeff Clark or Vic Chance**
Translucency	16 Levels
Texture	Cell texturing and stripe texturing. Upto sixteen 256 by 256 texture maps.
Polygons	4000 at 30 hertz 8000 at 60 hertz
Raster lights	Perspective, directional, strobe, VASI
Calligraphic lights	None
Moving models	15 maximum plus ownship. Six degrees of freedom each.

Ambient light	Day/dusk/night. 256 levels.
Haze/Visibility	0 - 16,900 feet at 10 foot intervals.
Clouds	1 cloud deck from 0 - 50,000 feet with 10 foot intervals. Scattered and overcast with top and bottom scud.
Horizon	For geocentric data bases. Horizon glow is a model that is position anywhere in the data base, so it does horizon glow or city glow.
Thunderstorm/Lightning	None
Special effects	20 projectiles 16 weapon effects 40 universal features
Sun angle shading	Fixed for mission, but can be modeled anywhere for continuous time of day. Range for sun angle is +/- 90 degree in 1 degree increments. No shadows.
Surface shading	Curved and smooth surface shading.
Anti-aliasing	4 by 4 subpixels
Visual range	Varies with visibility, 0 - 16,900 feet at 100 foot intervals. Fog from 0 - 16,900 feet in 10 foot intervals.
Level-of-detail ranges	8 levels
Occultation levels	4000 levels
Distracting effects	None
Update rate	60 or 30 hertz
Transport delay	60 milliseconds at 60 hertz
Postional range & accuracy	1/32 of a foot
Crash detection	Ownship and moving models
On-line data base	Approximately a 12 minutes by 12 minutes area.
DATA BASE ATTRIBUTES	**P.O.C. Jovan Raketich**
Geographic location	Washington State and Germany.
Scene density	Unknown for both data bases.
Model level-of -detail	3 levels of detail for each data base.
Moving models	For the Washington data base 4 models; MiG-27, SU-27, F-15, and F-16. For the Germany data base only an F-16 model.
Model library	Basic model library with each data base.
Airfield library	For the Washington data base - Chehalis and McChord (Seattle/Tacoma International airport is generic). For Germany - Ramstein.
Light models	Generic/basic library for each data base.
Data base size	For the Washington data base approximately 5700 sq nm with 1400 sq nm developed more than just terrain. For the Germany data base approximately 10,200 sq nm.
Airfield area size	Not the case for the Washington data base. 40 - 50 sq nm for the Germany data base.
Low altitude area size	None for each data base.
Air to ground area size	None for each data base.
Texture maps	For the Washington data base sixteen 256 by 256 maps. For the Germany data base fourteen 256 by 256 maps. Some are subdivided into lower resolution maps for each data base.
Accuracy	Unknown for each data base.
Polygon allocation	For each data base terrain has upto 256 faces per 12 minute by 12 minute area, and 22 - 23 models per terrain face.

Source data	For each data base DTED Level IC, DFAD, Photographs, and JOG charts were used.

Table E-2 Site 2 Detailed Hardware Description. (DART)

GENERAL	
Display Name	Mini - Display for Advanced Research and Development (Mini - DART)
Display type	Real image CRT projection (Barco 500 and 800 projectors). Total of 8 projectors used in rear screen projection for wrap around viewing.
Location	Armstrong Laboratory, Williams AFB AZ
Agency	Armstrong Laboratory, Williams AFB AZ
Image generator	Advanced Visual Technology System (AVTS) - Compu-Scene IV prototype.
Manufacturer	General Electric Company
DISPLAY ATTRIBUTES	**P.O.C. Mel Thomas**
Resolution	Front 3.32 arcminutes per pixel. Other seven 6.35 arcminutes per pixel. Front 5.07 arcminutes per line pair. Other seven 9.75 arcminutes per line pair.
Field of view	Azimuth : +/- 180 degrees Elevation : +90 degrees, -40 degrees
Brightness	50 foot-Lamberts forward channel and 15 foot-Lamberts side windows.
Contrast ratio	Greater than 100 : 1 50 : 1 with all screens illuminated
Collimation	Real image, flat screen viewing, 2 feet distance.
Geometric distortion	Less than 3%. No distortion correction algorithm.
Color Convergence	Adjusted for 0 error. Adjustable for proper registration.
Video signal-to-noise	
Sweep signal-to-noise	
Grey scale	
Colors	Full
Blemishes	Some - Did not affect viewing, they faded from perception.
Swimming	None
Spurious images	None
Image continuity	Edge matched across window boundaries (0 arcminutes).
Area-of-interest blending	None
HUD/Display focus	HUD information is electronically mixed with the forward window imagery.
HUD/Display correlation	HUD information is electronically mixed with the forward window imagery.
Refresh rate	60 hertz interlaced
Projector slew rate	N/A
Tracking ability	N/A
Viewing volume	N/A
IMAGE GENERATOR ATTRIBUTES	**P.O.C. Jeff Clark or Vic Chance**
Translucency	16 Levels
Texture	Cell texturing and stripe texturing. Upto sixteen 256 by 256 texture maps.

Polygons	4000 at 30 hertz 8000 at 60 hertz
Raster lights	Perspective, directional, strobe, VASI
Calligraphic lights	None
Moving models	15 maximum plus ownship. Six degrees of freedom each.
Ambient light	Day/dusk/night. 256 levels.
Haze/Visibility	0 - 16,900 feet at 10 foot intervals.
Clouds	1 cloud deck from 0 - 50,000 feet with 10 foot intervals. Scattered and overcast with top and bottom scud.
Horizon	For geocentric data bases. Horizon glow is a model that is position anywhere in the data base, so it does horizon glow or city glow.
Thunderstorm/Lightning	None
Special effects	20 projectiles 16 weapon effects 40 universal features
Sun angle shading	Fixed for mission, but can be modeled anywhere for continuous time of day. Range for sun angle is +/- 90 degree in 1 degree increments. No shadows.
Surface shading	Curved and smooth surface shading.
Anti-aliasing	4 by 4 subpixels
Visual range	Varies with visibility, 0 - 16,900 feet at 100 foot intervals. Fog from 0 - 16,900 feet in 10 foot intervals.
Level-of-detail ranges	8 levels
Occultation levels	4000 levels
Distracting effects	None
Update rate	60 or 30 hertz
Transport delay	60 milliseconds at 60 hertz
Postional range & accuracy	1/32 of a foot
Crash detection	Ownship and moving models
On-line data base	Approximately a 12 minutes by 12 minutes area.
DATA BASE ATTRIBUTES	**P.O.C. Jovan Raketich**
Geographic location	Washington State and Germany.
Scene density	Unknown for both data bases.
Model level-of -detail	3 levels of detail for each data base.
Moving models	For the Washington data base 4 models; MiG-27, SU-27, F-15, and F-16. For the Germany data base only an F-16 model.
Model library	Basic model library with each data base.
Airfield library	For the Washington data base - Chehalis and McChord (Seattle/Tacoma International airport is generic). For Germany - Ramstein.
Light models	Generic/basic library for each data base.
Data base size	For the Washington data base approximately 5700 sq nm with 1400 sq nm developed more than just terrain. For the Germany data base approximately 10,200 sq nm.
Airfield area size	Not the case for the Washington data base. 40 - 50 sq nm for the Germany data base.
Low altitude area size	None for each data base.
Air to ground area size	None for each data base.

Texture maps	For the Washington data base sixteen 256 by 256 maps. For the Germany data base fourteen 256 by 256 maps. Some are subdivided into lower resolution maps for each data base.
Accuracy	Unknown for each data base.
Polygon allocation	For each data base terrain has upto 256 faces per 12 minute by 12 minute area, and 22 - 23 models per terrain face.
Source data	For each data base DTED Level IC, DFAD, Photographs, and JOG charts were used.

Table E-3   Site 2 Detailed Hardware Description. (Mini-DART)

SITE 3: CAE STOLBERG, GERMANY (TORNADO)

GENERAL	
Display Name	Fiber Optic Helmet Mounted Display (FOHMD)
Display type	Head mounted, head and eye slaved, area-of-interest display system.
Location	CAE Germany, Stolberg, Federal Republic of Germany
Agency	CAE Electronics, Montreal Canada
Image generator	Evans and Sutherland ESIG-1000
Manufacturer	Evans and Sutherland, Salt Lake City, Utah
DISPLAY ATTRIBUTES	
Resolution	Head and eye-slaved Inset 1.5 arcmin per TV line Head slaved background 5.0 arcmin per TV line
Field of view	Inset : Instantaneous 18 degrees by 24 degrees horizontal Background : Instantaneous 66 degrees by 127 degrees horizontal
Brightness	Peak highlight brightness 30 ft-L
Contrast ratio	50: 1, optics only, w/o the combined background image. With balanced lighting, there is 3 ft-L of background illumination. With the above brightness, the contrast ratio is (30-3)/3 or 9: 1. Subjectively the contrast ratio is good.
Collimation	>10 meters
Geometric distortion	< 1.5% of picture height
Color Convergence	N/A. Video displayed using GE Talaria Light Valve. Inherently self-converged.
Video signal-to-noise	Estimated at 39 db.
Sweep signal-to-noise	N/A
Grey scale	9 levels. Not measured like the Air Force method using a non-linear grey scale. Each grey step is 1.41 times greater brightness than the next. Using this criteria the grey scale was about 7 steps, although no measurements were made.
Colors	Full color.
Blemishes	Blemishes due to fiber optic cable used for image transmission between light valve and helmet display, <0.1% in quality area. Black spots, due to cable strand breakage, throughout the field of view were noted.
Swimming	None.
Spurious images	None.
Image continuity	Individual eyepiece displays, overlapping 38 degrees in center of image field of view.
Area-of-interest blending	Yes, special video blending hardware to merge inset into background
HUD/Display focus	Both collimated. Helmet mounted display approximately 10% transmissive, HUD viewed normally through display.
HUD/Display correlation	As accurate as head position sensing permits (less than 0.2" in HUD area).
Refresh rate	60 Hertz.
Projector slew rate	N/A

Tracking ability	Optical head tracker with a resolution of 0.08 degrees in all rotational axes , and 0.01 inches in all translational axes. Rotational accuracy is 0.5 degrees and translational accuracy is 0.04 inches.
Viewing volume	15 mm pupil centered on each eye.
IMAGE GENERATOR ATTRIBUTES	
Translucency	Yes, 8 polygonal and 16 texture levels.
Texture	Yes, 128 (128 X 128) patterns on-line for polygonal texturing. Types of texture include full color, fixed, moving, and photographic. 64 texture motion systems available.
Polygons	2000 inset (one channel X 2000) 2400 background (two channels X 1200)
Raster lights	Yes, trade 3: 1 for polygons
Calligraphic lights	N/A
Moving models	8 six degrees of freedom prioritized dynamic coordinate systems. 8 six degrees of freedom range sorted dynamic coordinate systems. 10 six degrees of freedom system dynamic coordinate systems.
Ambient light	Day/Dusk/Night. Time of day can be changed once per minute with correlated sun azimuth and elevation also specified.
Haze/Visibility	Yes. Visibility is variable from 1 to 20 nautical miles, in increments of 1 foot. Fog is variable from 1 to 10 nautical miles, in increments of 1 foot.
Clouds	Yes. One cloud deck with top and bottom specified upto 44,000 feet, in increments of 1 foot. Scud is available.
Horizon	Yes
Thunderstorm/Lightning	Yes. Lights "double" due to rain. Lightning bolts and flashes are visible. One severity level.
Special effects	Air and ground explosions. IR flare, and tracers.
Sun angle shading	Yes. Sun azimuth and elevation can be specified by host computer once per minute. Shading will change according to sun angle.
Surface shading	Smooth shading can be applied to all 3 or 4 sided polygons.
Anti-aliasing	Yes. Sixteen sub-pixels.
Visual range	20 nautical miles maximum.
Level-of-detail ranges	Upto 32 level of details available. Typical 3 - 4 terrain (6/10/20 nm), and 3 culture (3 - 10 nm).
Occultation levels	Equal to the number of polygons.
Distracting effects	None
Update rate	60 hertz
Transport delay	66 2/3 milliseconds
Postional range & accuracy	1/512 foot
Crash detection	Yes. Collision of ownship with terrain, culture, and other moving models.
On-line data base	174,000 polygons per eyepoint (FOHMD).
DATA BASE ATTRIBUTES	
Geographic location	50 to 52 degrees north latitude 8 to 10 degrees east longitude

Scene density	Terrain: Low LOD 1.7 polygons/nm sq; Medium LOD 6.7 polygons/nm sq; High LOD 26.7 polygons/nm sq Culture: Low LOD 16 polygons/nm sq; Medium LOD 600 polygons/nm sq
Model level-of -detail	Not available.
Moving models	MRCA, MiG-23, MiG-29, F-4, SA-8,T-80, and ZSU-23/4
Model library	Fishbed, Backfire, T-72, F-15, F-16, CH-53, B0105, HIND, M-1, M-2, SA-9, ZSU-57, and BMP.
Airfield library	Lechfeld and Neuburg.
Light models	Cultural lights, airfield lights, beacons, etc.
Data base size	30,000 square kilometers
Airfield area size	As per airfield, included in geographic data base.
Low altitude area size	Two enhanced regions approximately 10 X 30 nautical miles each
Air to ground area size	Bomb range at Muensingen
Texture maps	128 (128 X 128) maps available
Accuracy	1/512 of a foot.
Polygon allocation	Not available.
Source data	DMA DTED/DFAD Level 1 1:50,000 maps and 1: 250,000 JOG charts Photographs

Table E-4   Site 3 Detailed Hardware Description. (FOHMD)